

ATTACHMENT E

GOES HYPERSENSITIVE ENVIRONMENTAL SUITE (HES)

PERFORMANCE AND OPERATION REQUIREMENTS DOCUMENT (PORD)

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GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GREENBELT, MARYLAND

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**GOES
HYPERSENSITRAL ENVIRONMENTAL SUITE**

**PERFORMANCE AND
OPERATION REQUIREMENTS DOCUMENT**

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1 SCOPE

1.1 IDENTIFICATION

This Sensor Performance and Operations Requirements document sets forth the performance requirements for the NOAA Hyperspectral Environmental Suite (HES).

1.2 DOCUMENT OVERVIEW

This document contains all performance requirements for the sensor except those labeled “TBD,” “TBS,” and “TBR”. The term “TBD,” meaning "to be determined," applied to a missing requirement means that the contractor should determine the missing requirement in coordination with the government. The term “TBS,” meaning "to be specified," indicates that the government will supply the missing information in the course of the contract. The term “TBR,” meaning "to be reviewed," implies that the requirement is subject to review for appropriateness by the contractor or the government. The government may change “TBR” requirements in the course of the contract.

1.2.1 Requirement Weighting Factors

The requirements stated in this specification are not of equal importance or weight. The following two paragraphs define the weighting factors incorporated in this specification.

- **Shall** designates the most important weighting level, which is *mandatory*. Any deviations from these contractually imposed mandatory requirements require the approval of the contracting officer.
- **Should** designates an intermediate weighting that indicates the requirements requested by the government are not mandatory. These are GOAL requirements that would greatly enhance the utility of the data if they were met. Unless required by other contract provisions, noncompliance with the should requirements does not require approval of the contracting officer, but requires documented technical substantiation.

Goal requirements should be approached, met, or exceeded as practical.

1.2.2 Conflicts

In the event of conflict between the applicable documents and the contents of this document, the contents of this requirements document **shall** be the superseding requirements.

In the event of a conflict involving the external interface requirements, or in the event of any other unresolved conflict, the NASA contracting officer will determine the order of precedence.

1.2.3 Reserved

1.2.4 Requirements Applicability

All requirements **shall** apply over the entire life of the HES.

All requirements in this document apply to data after any ground processing except as indicated.

1.2.5 Reserved

1.3 MISSION OVERVIEW

*Discussion: A main goal of GOES-R is to maintain continuity of GOES service to users and user agencies and to upgrade services. The weather and environmental monitoring instruments of GOES-R include at least the Advanced Baseline Imager (ABI) and the Hyperspectral Environmental Suite, designated HES in this document. The HES is **any combination of instrument or instruments that meet the requirements described in this document**. It is anticipated that the instrument(s) meeting the disk sounding (DS) and severe weather/mesoscale (SW/M) tasks of this document will be either a dispersive spectrometer or an interferometric spectrometer, or both.*

The HES suite will provide data to the HES Ground System, designated as HES-GS in this document, via the spacecraft communication system. The HES-GS will be procured by the government but may implement algorithms developed by the vendor to satisfy HES performance requirements. The required algorithms are discussed in the SOW. It is also the task of the vendors to determine an INR budget that meets the INR requirements.

Specific tasks are broken down as follows.

1.3.1 THRESHOLD Tasks

The HES will provide the following THRESHOLD tasks: two sounding tasks, which include disk sounding (DS) and severe weather/mesoscale sounding (SW/M), and a shelf and coastal waters imaging task (CW).

Discussion: These tasks provide the following information:

- a) Provide vertical moisture and temperature information, and other environmental data that will be used by NOAA and other public and private agencies to produce routine meteorological analyses and forecasts (DS, SW/M).*
- b) Provide environmental data that can be used to expand knowledge of mesoscale and synoptic scale storm development and provide data that may be used to help in forecasting severe weather events (SW/M).*

- c) *Provide data that may be used to extend knowledge and understanding of the atmosphere and its processes (e.g., by viewing the evolution and motion of storms and other atmospheric phenomena) in order to improve short/long-term weather forecasts (DS, SW/M).*
- d) *Provide information about ocean color and optical properties, and as a goal, sea surface temperature (CW).*

1.3.2 Goal Task

The HES may provide the following GOAL task: open ocean (OO) imaging.

Discussion: This task will provide information about ocean current, offshore ocean color, offshore optical properties, and offshore sea surface winds.

2 REFERENCE AND APPLICABLE DOCUMENTS

2.1 Reference Documents

The following documents provide background and context for this HES RFP specification. Information is now be available on the HES document web site http://goes1.gsfc.nasa.gov/HES_docs.htm or from the GOES HES project library at NASA/GSFC by contacting the GSFC GOES Program Office at (301)-286-9840.

2.2 Applicable Documents

3 INSTRUMENT REQUIREMENTS

3.1 General

3.1.1 HES Overview and Description

Discussion: The HES instrument(s) are designed to sense emitted thermal energy and reflected solar energy from sampled areas of the Earth's surface and atmosphere. These data are used to compute vertical profiles of temperature and moisture, surface and cloud-top temperatures, and winds, and provide information about the Earth surface and oceans. The HES is part of a 3-axis stabilized, geostationary satellite system that collects weather and environmental data, in conjunction with data from an imaging instrument, to aid in the prediction of weather and climate monitoring. The HES data, depending on the task, provide moderate to high spatial resolution, high spectral, temporal and radiometric resolution to accurately monitor rapidly changing environmental conditions including coastal waters and rapidly changing weather.

The requirements in this document pertain to the HES 'system', which may include scanner, optics, detectors, signal processing electronics and software, and ground processing. The HES vendor is not responsible for the whole HES-GS, but certain specifications will require some level of ground processing after collection but before data distribution, i.e. calibration and navigation, and such ground processing may require vendor supplied instrument-dependent algorithms.

3.1.1.1 Critical Definitions

- Detector Sample: Digitized output from a single detector element.
- Spectral Sample: A measurement within a channel that may or may not be aggregated for transmission to the ground.
- Channel: A measurement within a band that is an aggregate of one or more spectral samples that meets or exceeds HES threshold requirements.
- Threshold Channel: A channel with a HES threshold spectral resolution element width. (see section 3.2.2)
- Pixel: All spectral channels associated with a given spatial resolution element after processing, including calibration and navigation.
- Band: A set of channels (see section 3.2.2.1)

3.1.2 Top level functions

The HES performs the following functions:

- Scene IR spectroscopy
- Imaging

- Radiometric calibration of spectroscopic and imaged data
- Star sensing, if required to meet navigation requirements.
- On-orbit monitoring of calibration sources and instrument response changes
- Acquisition of sensor health and status data
- Generation of sensor, calibration, monitoring, health and status data streams
- Reception and execution of command and control data

3.1.3 HES Modes

All HES Modes and their functions **shall** be documented in the Instrument Definitions Document (IDD).

The HES **shall** include ground commands to individually enable and disable each autonomous function of the HES.

The HES **shall** initiate all commanded mode transitions in no more than 10 seconds after receipt of command, except for transitions to Safe Mode.

Transitions to Safe Mode, whether commanded or autonomous, **shall** require no more than 1 second to initiate.

Transitions to Safe Mode, whether commanded or autonomous, **shall** require no more than 60 seconds to complete.

Table 3.1.1 Reserved

3.1.3.1 Reserved

3.1.3.2 Normal Operational Mode

The HES **shall** implement a Normal Operational Mode upon ground command.

In Normal Operational Mode, the HES **shall** be in a fully functional configuration and capable of all requirements presented in section 3.2.

3.1.3.2.1 Idle State

In the Idle State, the HES **shall** be in a fully functional configuration with the exception that moving mirrors (if present) are not scanning.

In the Idle State, the scan mirrors (if present) **shall** be parked at commandable gimbal angles that are stored in the HES's reprogrammable nonvolatile memory.

3.1.3.2.2 Commanded Reset

The HES **shall** be interruptible by a reset command that ceases current operations and causes the HES to enter the Idle State.

3.1.3.2.3 Instrument Diagnostic State

The HES **shall** implement an Instrument Diagnostic State.

In the Instrument Diagnostic State, the HES **shall** be in a fully functional configuration.

Furthermore, in the Instrument Diagnostic State, the HES **shall**, as a minimum, have the following capabilities:

- Increase the sampling rate of selected critical telemetry points for anomaly investigation.
- Acquire data while scanning with TDI (if used) inhibited or enabled.
- In those cases where TDI data is digitally processed off the focal plane in the HES, be capable of sending the individual measurements for ground assessment.
- Be capable of sending data from any subset of detectors.
- Be capable of sending the same data, both compressed and uncompressed, to allow ground evaluation of the impact of compression on the data.
- If low order bits from the A/D converter are typically not sent to the spacecraft, transmission of these bits shall be afforded.

Discussion: In all of the above requirements, the data to be sent to the spacecraft will be selected to stay within the allocated data rate. The acquisition of this data will be done in a manner that does not require any design modification of the focal planes and their readout systems from their nominal design.

3.1.3.3 ABI Back-up Mode

A wing is either the western or eastern full disk view that is not covered by a central full disk view (nominally $1.91 \times 10^7 \text{ km}^2$ as shown in Figure 3.1.1 with a maximum width of 2806 km (TBS)).

Overview: In the event that an Advanced Baseline Imager (ABI) fails in orbit, and can no longer produce critical image products, HES may be tasked to provide backup to the ABI. The functional ABI has been moved to the central position nominally at 105 degrees W.

The ABI backup mode will provide both coverage of 1 and 2 below: 1) imaging of either west or east wing and 2) soundings over the 62 degree LZA meeting the requirements of the DS task, employing the ABI Back-up Mode NEdN requirement below. The imaging of the wing **shall** be completed every 30 minutes (THRESHOLD). The sounding of the standard DS task, defined in subsequent sections, shall meet or exceed the DS task GSR requirements.

The GSD for the ABI back-up mode **shall** be less than or equal to 4 km for the emissive bands.

The GSD for the ABI back-up mode **shall** be less than or equal to 4 km any reflective solar bands that are not the visible band.

The GSD for the ABI back-up mode **shall** be less than or equal to 1 km for the visible band.

ABI Back-up Mode NEDN **shall** be “what the vendor can provide”, which is constrained here for imaging and for sounding. “What the vendor can provide” **shall** include the *subset* of ABI band coverage included in the vendor’s HES: visible band, reflected solar $< 1 \text{ um}$ (or reflective solar $< 3 \text{ um}$), and emissive IR bands (THRESHOLD).

As a GOAL, the HES should provide, when imaging in the ABI back-up mode, the noise performance of the subset of ABI bands contained in the vendor’s HES; and should provide for sounding the noise performance of $2 \times \text{NEDN}$ (TBR) of the DS task. (GOAL).

The ABI back-up mode **shall** not preclude the usage of the SW/M task or the HES-CW task.

See the ABI PORD for ABI capabilities.

Discussion: The ABI back-up mode is being studied and it may be invoked in the event of an ABI failure.

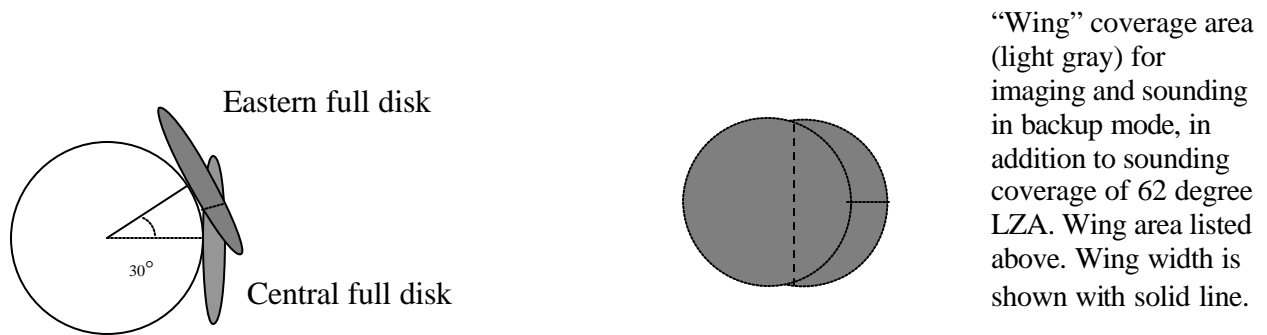


Figure 3.1.1 (Left) Polar view of earth showing eastern full disk coverage and central full disk coverage in a failure scenario for the western A satellite in the distributed architecture. (Right) Equatorial view of ABI coverage from central disk and HES backup coverage (or “wing” coverage) from eastern satellite.

3.1.3.4 Outgas Mode

The HES **shall** implement an Outgas Mode. Initial outgas will occur after the GOES-R series satellite has successfully reached its on-station orbit and the solar array has successfully deployed.

The Outgas mode **shall** be utilized to outgas and evaporate contaminants from HES hardware to prevent contamination from jeopardizing HES performance.

During the Outgas Mode when the aperture door is open, the HES **shall** be in a fully functional configuration and be capable of meeting all requirements for channels $< 1 \text{ } \mu\text{m}$.

3.1.3.5 Reserved

3.1.3.6 Reserved

3.1.4 Operational Concept

3.1.4.1 Reserved

3.1.4.1.1 Reserved

3.1.4.1.2 Reserved

3.1.4.2 On-orbit Operations

The HES **shall** interrupt current operations by command and start the acquisition of a new frame, after a frame coordinate upload, within 30 (TBR) seconds.

Discussion: The HES will fly aboard a 3-axis stabilized, geostationary spacecraft with orbital constraints specified in the HES GIRD/UIID. Regular operations consist of star sensing, if required, and acquiring data from: 1) selectable ground sources (e.g., to perform the DS, SW/M, CW and OO, if implemented, tasks), 2) non-routine variable size and source areas, and 3) calibrations.

3.1.4.3 Zones of Reduced Data Quality

3.1.4.3.1 Operational Zone

The HES **shall** meet all of its operational requirements for all pixels greater than the THRESHOLD limits in Table 3.1.2 from the center of the uneclipsed Sun.

The HES should meet all of its operational requirements for all pixels greater than the GOAL limits in Table 3.1.2 from the center of the uneclipsed Sun.

Thorough analysis and innovative designs are encouraged to minimize the outer limit. See Figure 3.1.2 for a pictorial description for both sections 3.1.4.3.1 and 3.1.4.3.2.

Table 3.1.2 THRESHOLD and GOAL Operational Zones

Channels	Limit Operational Zone (THRESHOLD)	Limit Operational Zone (GOAL)
Emitted IR channels (650-2720 cm ⁻¹)	10° (TBR)	5° (TBR)
Low light (visible)	10° (TBR)	5° (TBR)

3.1.4.3.2 Restricted Zone

The HES **shall** meet all requirements, except the NEdN and On-Orbit calibration and accuracy sections, for all pixels between the THRESHOLD limit in Table 3.1.3 and the THRESHOLD limit of Table 3.1.2, measured from the center of the uneclipsed Sun.

The HES should meet all requirements, except the NEdN and On-Orbit calibration and accuracy sections, for all pixels between the Goal limit in Table 3.1.3 and the Goal limit of Table 3.1.2, measured from the center of the uneclipsed Sun.

Table 3.1.3 THRESHOLD and GOAL Restricted Zones

Channels	Outer Limit Restricted Zone (THRESHOLD)	Outer Limit Restricted Zone (GOAL)
Emitted IR channels (650-2720 cm ⁻¹)	3° (TBR)	2° (TBR)
Low light (visible)	3° (TBR)	2° (TBR)

Reflected solar (<3 um) are not required over the coverage area whenever any point on the coverage area falls within the Zone of Reduced Data Quality.

In place of the NEdN, dynamic range, and On-Orbit calibration and accuracy sections, the HES **shall** meet the following requirements:

- NEdN < 2x normal specification.
- Detectors **shall** not saturate.
- Calibration performance **shall** not degrade by more than TBD (THRESHOLD) and 0.5 K (Goal).

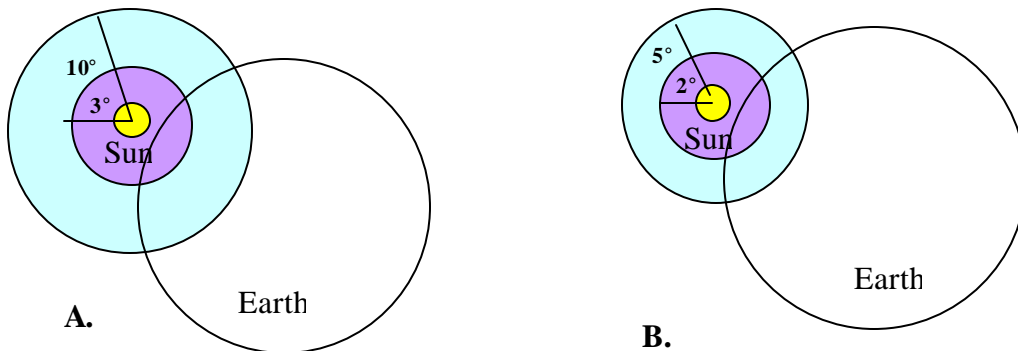


Figure 3.1.2. Pictorial of A. THRESHOLD (shall) and B. GOAL (should) operational and restricted zones.

3.1.4.3.3 Scanning across the Sun

Ground operations will not routinely scan any detector of the HES closer than 1.4 (TBR) degrees from the center of the Sun.

3.1.4.4 Reserved

3.1.4.5 Eclipse

During eclipse, the HES **shall** meet all requirements for channels > 3 um.

3.1.4.6 Flexible and Efficient Scan Pattern

3.1.4.7 Operations After Maneuvers

3.1.4.7.1 Yaw Flip

The HES **shall** meet INR requirements (section 3.2.8) within 1 day after the yaw flip.

Discussion: If required for meeting instrument envelope and radiometric performance requirements, the GOES spacecraft may be rotated 180° twice per year, within ± 4 (TBR) days of the Sun crossing the plane of the orbit, so that the solar loading on the instrument radiative coolers is reduced. The rotation will be performed any time during the 8 (TBR) day window and will be carried out such that neither the Sun nor Earth illuminates the cooler during the maneuver. The maneuver is expected to last less than 1 (TBR) hour. The net effect reverses the sign of the roll and pitch axis while maintaining yaw pointing at nadir.

3.1.4.7.2 Stationkeeping

The HES **shall** meet all radiometric, coverage, and INR requirements within 60 minutes (TBR) after the spacecraft interface has returned to being within specification following spacecraft North-South stationkeeping maneuvers.

3.1.4.7.3 Post Storage Activation

The HES **shall** meet all requirements within 5 (TBR) days of HES turn on after post storage activation for a HES with passively cooled detectors and 3 (TBR) days for a HES with actively cooled detectors.

3.1.4.8 Infrared Detector Operating Temperatures

The operating thermal margin of the detector cooling system **shall** be based on heat loads. Detector operating thermal margin is the calculated excess system cooling capability versus the heat load including EOL dissipations, parasitics and external fluxes.

The following operating thermal margins shall be maintained in detector cooling margin:

- 50% up to and including the phase design
- 45% up to and including PDR
- 40% up to and including CDR
- 30% thereafter including test

For multistage cooling systems, the margins apply to all stages simultaneously. After test, the 30% margin shall be maintained as operation and excess contamination margin.

The detector operation temperatures **shall** be selectable by command.

The tolerance on the control temperatures accuracy **shall** be to +/- 0.5K.

The HES is not required to meet the NEdN/NEdT specifications when the detectors are operated above their nominal temperature.

3.1.4.9 Reserved

3.1.5 Reserved

3.1.6 Data Compression

Data compression of HES data, derived from all tasks, **shall** be selectable between lossless compression (~2:1) and lossy compression (~4:1, or possibly higher). The acceptable criteria are TBD.

Discussion: Such user selectibility will enable user comparison and evaluation of the suitability of lossy compression schemes.

3.1.7 Lifetime and Reliability

The HES **shall** have a reliability of 0.6 after ten years of operations, 5 years on orbit storage and 5 years of ground storage. The mean mission duration (MMD), namely the integrated area under the reliability versus time curve, for the instrument **shall** be 8.4 years.

3.2 NORMAL OPERATIONAL MODE SENSOR REQUIREMENTS

3.2.1 Scope

It is emphasized again that there are three THRESHOLD tasks in the normal mode of operations that are outlined in section 1.3: two hyperspectral sounding tasks (DS and SW/M), and one hyper- or multi- spectral imaging task (CW). The sensor requirements presented below pertain to these tasks. When the DS and SW/M task requirements are grouped together, they are identified as “sounding” requirements. Sensor requirements for the GOAL task are addressed in appendix A.

Discussion: When appropriate, a single requirement is specified and applied to all tasks. Task specific requirements are uniquely identified in each section, i.e.

the ground sample distance requirement is unique to each task. Finally, there are some requirements that only apply to a single task, and they are appropriately identified.

As previously stated, the measurement requirements for the HES could be met with a single integrated sensor or with multiple sensors, each dedicated to a task. It is anticipated that the instrument(s) meeting the DS and SW/M tasks of this document will be either a dispersive spectrometer or an interferometric spectrometer, or both. The government has decided not to discriminate against one method over another. As such, the requirements in this section are written so that no particular architecture is preferred.

Discussion: This section of the document attempts to present requirements that allow design flexibility in that regard. It is also recognized that there are several ways to collect spectral data. This causes some difficulty when trying to specify unambiguous requirements. Apparent ambiguities arise from the fact that the attributes of the collected data depend (to some extent) on the collection method, i.e. whether a dispersive or multiplexing spectrometer is used. An effort was made to avoid ambiguous requirements; therefore it was necessary to make certain basic assumptions in order to assimilate a reasonably bound set of sensor requirements. Some of the relevant assumptions are described in sections (2.10.2) 2.A and (2.10.2) 3.B.2.g of the MRD. These assumptions are referenced for insight only, and do not mandate particular design features.

Discussion: With these instrument assumptions, to first order, the achievable radiometric performance of the HES depends only on the ground sample rate (GSR) requirement. In this document, the GSR and radiometric performance (NE Δ N and SNR in section 3.2.7.2) are considered the most fundamental performance requirements. The operational implementation of HES, however, will utilize a variety of coverage areas and spatial sampling implementations. Ideally, the HES would arbitrarily trade coverage area, coverage time, and spatial resolution per frame, while maintaining GSR and radiometric performance.

For the purpose of presenting a well-defined sensor to potential contractors, the government has decided to envelope these operationally variable parameters based on the envisioned typical tasks, i.e. DS, SW/M and CW. The THRESHOLD coverage area capabilities are presented in section 3.2.4. The THRESHOLD sampling capabilities are presented in section 3.2.5. The THRESHOLD coverage time capabilities for each coverage region are presented in section 3.2.6.1.

3.2.2 Spectral Requirements

3.2.2.1 Number of Spectral Bands

Discussion: The number of spectral bands describes how many spectral regions are covered in the sensor(s). The requirement does not dictate the number of

unique detector elements or focal planes or optical paths within the sensor. It is acceptable to design the sensor such that multiple bands are imaged onto a single detector or focal plane, e.g. the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) combines the SWIR and MWIR bands into a single SW/MW-IR band (see bands 2 and 3 below). Conversely, separating bands and imaging onto multiple focal planes is also an acceptable approach. The bands are consecutively numbered below. This enumeration defines the HES band number referenced throughout the rest of this document. For more information, see section (2.10.2) 3.B.2.g of the MRD.

As a THRESHOLD, the sounding task sensor(s) **shall** have four (4) spectral band observations:

1. A Long-Wave infrared (LWIR) band primarily for temperature sounding, skin surface temperature, and tracers employing ozone.
2. A Mid-Wave infrared (MWIR) band primarily for water vapor sounding.
3. A Short-Wave infrared (SWIR) band primarily for sounding the mid to lower troposphere, surface skin temperature, and detection of thin cirrus.
4. A Visible (Reflected Solar) band primarily for cloud clearing.

As a GOAL, the sounding task sensor(s) SWIR band (HES band 3) should also provide additional shortwave coverage as detailed later in the document for enhanced retrieval performance in the troposphere as well as improved atmospheric soundings in the presence of clouds.

As a GOAL, the sounding task sensor(s) should also provide both MWIR options, defined in Table 3.2.1.

As a THRESHOLD, the CW task sensor **shall** have one (1) spectral band:

5. A Reflected Solar $< 1 \mu\text{m}$ band for coastal ocean color and other measurements outlined in the MRD.

As a GOAL, the CW task sensor should also include two (2) additional bands:

6. Reflected Solar $> 1 \mu\text{m}$ band for measuring cloud properties.
7. A LWIR band for sea surface temperature measurements co-located with the color measurement.

3.2.2.2 Spectral Range

Discussion: Since sounders measure the absorption features of atmospheric constituents to retrieve temperature and water vapor profiles, it is not possible to specify a unique set of spectral channels to meet retrieval requirements. There are several possible channel sets that can be used with the appropriate models to produce acceptable profiles. Refer to the MRD for more details. The optimal

channel set then depends on the type of sensor used to acquire the data, the noise characteristics, and the specific algorithms used to process the radiances into profiles. As a result, the THRESHOLD requirements for the sounding sensor(s) are presented in a way that allows flexibility in the water vapor sounding region where heritage sensors have operated or are planned in two distinct spectral regions within the MWIR band. Two options are presented for the MWIR band. Also included in the table is a band continuity requirement. It mandates either contiguous or non-contiguous spectral sampling within each band. Note that although contiguous bands are mandated for some, there are acceptable limits for missing channels. These limits are presented in the spectral band breaks section 3.2.2.7 and spectral operability section 3.2.7.2.1.

As a THRESHOLD, the sounding task sensor(s) band **shall** conform to the band limits and continuity presented in Table 3.2.1. Either MWIR spectral band option presented in the table is acceptable.

Discussion: It is also acceptable to split the MWIR spectral range between the two contiguous options, provided the water vapor vertical profile derived from the absorption feature is sufficiently covered, as described in the MRD, section (2.10.2) 3.B.2.g.

Table 3.2.1 Sounding sensor(s) THRESHOLD bands.

Band	HES Band Number	Spectral Range (cm⁻¹)	Spectral Range (um)	Band Continuity
LWIR	1	650 – 1200	15.38 - 8.33	Contiguous
MWIR (option 1)	2	1650 – 2150	6.06 - 4.65	Contiguous
MWIR (option 2)	2	1210 – 1740	8.26 - 5.74	Contiguous
SWIR	3	2150 – 2250	4.65 - 4.44	Contiguous
VIS	4	NA	0.52 - 0.70	Contiguous

As a GOAL, the sounding task sensor(s) MWIR contiguous spectral range (HES band 2) should be 1210 – 2150 cm⁻¹ (8.26 – 4.65 um). As a GOAL, the sounding task sensor(s) SWIR contiguous spectral range (HES band 3) should be 2150 – 2720 cm⁻¹ (4.65 – 3.68 um).

Discussion: This will allow the improvements listed in MRD section (2.10.2) 3.B.2.g.

As a THRESHOLD, the CW task sensor spectral range (HES band 5) **shall** conform to the values and continuity presented in Table 3.2.2. Specific channels, and the resolution of each, are designated in section 3.2.2.3.

Table 3.2.2 CW task sensor THRESHOLD band.

Band	HES Band Number	Spectral Range (um)	Band Continuity
Reflected Solar < 1 um	5	0.4 – 1.0	Non-contiguous

As a GOAL, the CW task sensor band limits should conform to the values and continuity presented in Table 3.2.3. Specific channels, and the resolution of each, are designated in section 3.2.2.3 for the LWIR band 7.

Table 3.2.3 CW task sensor GOAL bands.

Band	HES Band Number	Spectral Range (cm⁻¹)	Spectral Range (um)	Band Continuity
Reflected Solar < 1 um	5	NA	0.40 - 1.0	Contiguous
0.570 um	5	NA	0.565-0.575	Non-Contiguous
Reflected Solar > 1 um (option 1-CW)	6	NA	1.0 - 2.285	Contiguous
Reflected Solar > 1 um (option 2-CW)	6	NA	1.35-1.41, 1.55-1.67, 2.235-2.285	Non-contiguous
LWIR	7	813 - 893	11.2 – 12.3	Non-contiguous

3.2.2.3 Resolving Power

The achieved spectral resolution element is defined as the full-width-half max of the instrument line-shape function (ILS) for filter or dispersive implementations ($\Delta\lambda$ μm), or one half the distance between the first minima of the unapodized line-shape function (ideally a Sinc function) for a multiplexing implementation ($\Delta\nu$ cm^{-1}). The definitions in Section 3.1.1.1 levy equivalent requirements on both instrument types.

There **shall** be at least one spectral sample for each threshold channel. Planned gaps between channels within a band are permissible subject to the limitations in section 3.2.2.7.

Non-contiguous bands are specified in terms of the individual channel centers and the full-width-half max resolution ($\Delta\lambda$ μm) for each.

Contiguous bands are specified in terms of the effective instrument spectral resolving power (\mathfrak{R}) for all points within the band limits:

$$\mathfrak{R} \equiv \frac{\lambda}{\Delta\lambda} = \frac{\nu}{\Delta\nu},$$

Equation 3.2.1

where λ is the wavelength in a dispersive system and ν is the wavenumber in a multiplexing system. The instrument spectral resolving power is specified at discrete points within each band. As defined here, \mathfrak{R} is a property of the instrument, i.e. not the dispersive element alone in a grating implementation. The specification for intermediate channels is found by linear interpolation in wavenumber space.

The achieved resolving power for the sounding task sensor(s) **shall** be greater than or equal to the THRESHOLD values listed in Table 3.2.4, Table 3.2.5, and Table 3.2.6.

The achieved resolving power for the sounding task sensor(s) should be greater than or equal to the GOAL values listed in Table 3.2.4, Table 3.2.5, and Table 3.2.6.

As a THRESHOLD, the sounding task sensor(s) LWIR band (HES band 1) resolving power **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.1 (solid line).

As a GOAL, the sounding task sensor(s) LWIR band (HES band 1) resolving power should be greater than or equal to the GOAL values (dashed line). Values for key wavelengths are quantified in Table 3.2.4.

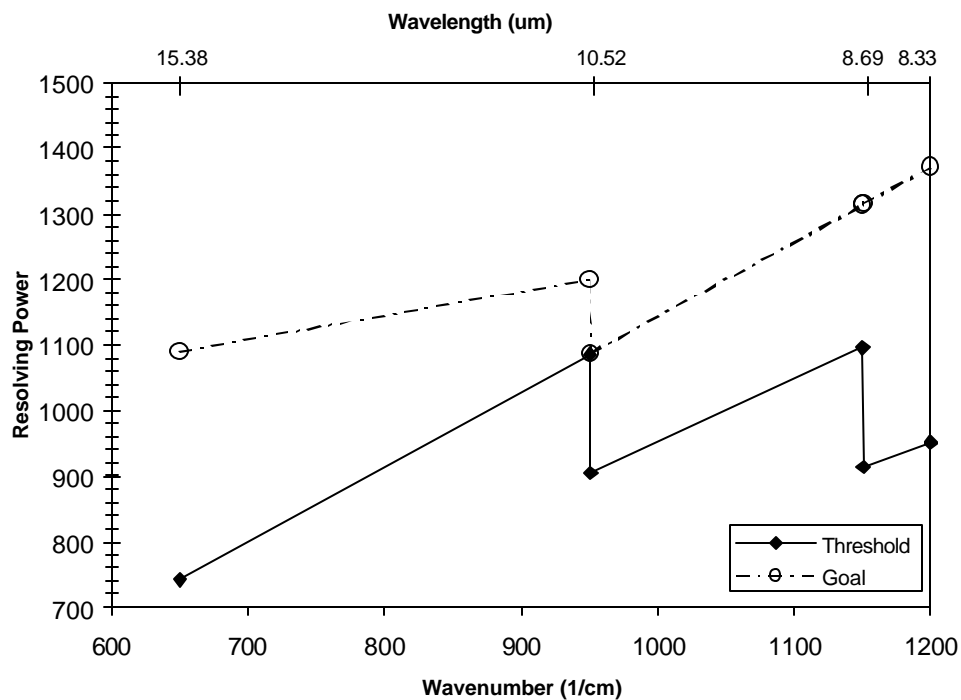


Figure 3.2.1 Plot of sounding sensor(s) LWIR band spectral resolving power requirement.

Table 3.2.4 Sounding sensor(s) LWIR band spectral resolving power requirement.

Wavenumber (cm ⁻¹)	Wavelength (um)	THRESHOLD	GOAL
650	15.38	743	1090(TBS)
950	10.53	1086	1200(TBS)
951	10.52	905	1087
1150	8.70	1095	1314
1151	8.69	914	1315
1200	8.33	952	1371

As a THRESHOLD, the sounding task sensor(s) MWIR band (HES band 2) resolving power **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.2 (solid line).

As a GOAL, the sounding task sensor(s) MWIR band (HES band 2) resolving power should be greater than or equal to the GOAL values (dashed line). Values for key wavelengths are quantified in Table 3.2.5.

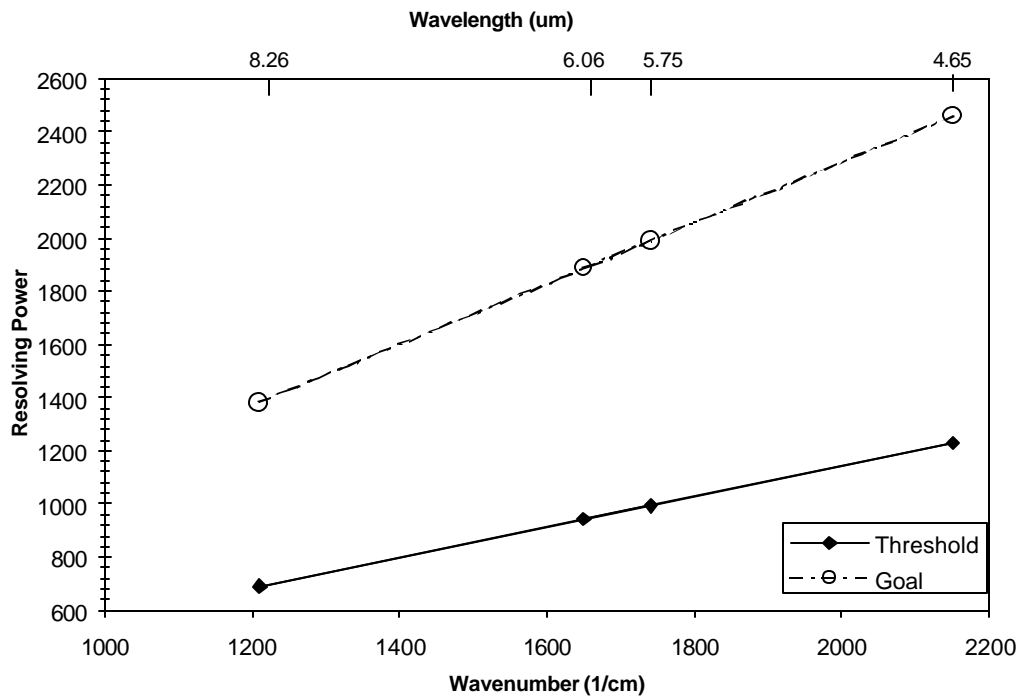


Figure 3.2.2 Plot of sounding sensor(s) MWIR band spectral resolving power requirement.

Table 3.2.5 Sounding sensor(s) MWIR band spectral resolving power requirement.

Wavenumber (cm ⁻¹)	Wavelength (um)	THRESHOLD	GOAL
1650	6.06	943	1886
2150	4.65	1229	2457
1210	8.26	691	1383
1740	5.75	994	1989

As a **THRESHOLD**, the sounding task sensor(s) SWIR band (HES band 3) resolving power **shall** be greater than or equal to the **THRESHOLD** values plotted in Figure 3.2.3 (solid line).

As a **GOAL**, the sounding task sensor(s) SWIR band (HES band 3) resolving power should be greater than or equal to the **GOAL** values (dashed line). Values for key wavelengths are quantified in Table 3.2.6.

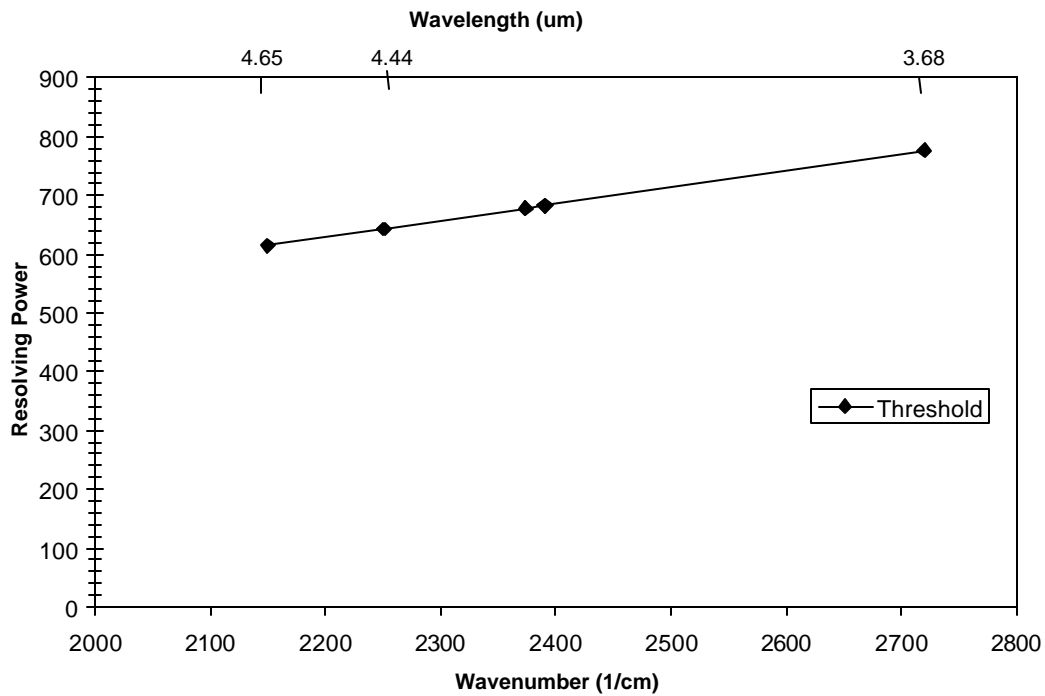


Figure 3.2.3 Plot of sounding sensor(s) SWIR band spectral resolving power requirement.

Table 3.2.6 Sounding sensor(s) SWIR band spectral resolving power requirement.

Wavenumber (cm ⁻¹)	Wavelength (um)	THRESHOLD	GOAL
2150	4.65	614	TBS
2250	4.44	643	TBS
2720	3.68	777	TBS

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) spectral resolution **shall** be less than (finer) or equal to 0.18 um.

As a THRESHOLD, the CW task sensor Reflected Solar < 1 um band (HES band 5) channel center and spectral resolution **shall** conform to the values presented in Table 3.2.7.

Table 3.2.7 CW sensor THRESHOLD spectral resolution.

Nominal Threshold Channel Center Wavelength (um)	Nominal Threshold Resolution (um)	Threshold tolerance on center wavelength (um)	Lower 50% Response Point Threshold	Upper 50% Response Point Threshold
0.412	0.02	+/- 0.002 (TBR)	0.402 +/- 0.0015	0.422 +/- 0.0015
0.443	0.02	+/- 0.0011 (TBR)	0.433 +/- 0.0015	0.453 +/- 0.0015
0.477	0.02	+/- 0.002 (TBR)	0.467 +/- 0.0015	0.487 +/- 0.0015
0.490	0.02	+/- 0.0012 (TBR)	0.480 +/- 0.0015	0.500 +/- 0.0015
0.510	0.02	+/- 0.0015 (TBR)	0.500 +/- 0.0015	0.520 +/- 0.0015
0.530	0.02	+/- 0.0012 (TBR)	0.520 +/- 0.0015	0.540 +/- 0.0015
0.550	0.02	+/- 0.005 (TBR)	0.540 +/- 0.0015	0.560 +/- 0.0015
0.645	0.02	+/- 0.004 (TBR)	0.635 +/- 0.0015	0.655 +/- 0.0015
0.667	0.01	+0.001-0.002 (TBR)	0.662 +/- 0.0015	0.672 +/- 0.0015
0.678	0.01	+/- 0.001(TBR)	0.673 +/- 0.0015	0.683 +/- 0.0015
0.750	0.02	+/- 0.002 (TBR)	0.740 +/- 0.0015	0.760 +/- 0.0015
0.763	0.02	+/- 0.0015 (TBR)	0.753 +/- 0.0015	0.773 +/- 0.0015
0.865	0.02	+/- 0.0022 (TBR)	0.855 +/- 0.0015	0.875 +/- 0.0015
0.905	0.035	+/- 0.0023 (TBR)	0.887 +/- 0.0015	0.922 +/- 0.0015

As a GOAL, the CW task sensor(s) spectral resolution for both the non-contiguous bands and the GOAL contiguous bands should be 0.01 um for the CW task threshold channels.

As a GOAL, the CW task sensor(s) spectral resolution and number of channels should conform to the values presented in Table 3.2.8. Note that the *contiguous* implementation of the reflective solar < 1 um band **shall** afford a channel centered at 0.667 um, as described in the table below, and also at 0.570 um.

Table 3.2.8 CW sensor GOAL spectral resolution.

Band	HES Band Number	Nominal GOAL Channel Center Wavelength (um)	Nominal GOAL Resolution (um)	Threshold tolerance on center wavelength (um)	Lower 50% Response Point Threshold	Upper 50% Response Point Threshold
Reflected Solar < 1 um	5	0.407 through 0.987	0.01	+/- 0.001 (TBR), centered on 0.667 +/- 0.001	+/- 0.0015, e.g 0.662 +/- 0.0015	+/- 0.0015, e.g 0.672 +/- 0.0015
0.570	5	0.570	0.01	+/- 0.001 (TBR), centered on 0.570 +/- 0.001	+/- 0.0015, e.g 0.565 +/- 0.0015	+/- 0.0015, e.g 0.575 +/- 0.0015
Reflected Solar > 1 um	6	1.38	0.03	+/- 0.005 (TBR)	1.35 +/- 0.005	1.41 +/- 0.005
Reflected Solar > 1 um	6	1.61	0.06	+/- 0.005 (TBR)	1.55 +/- 0.01	1.67 +/- 0.01
Reflected Solar > 1 um	6	2.26	0.05	+/- 0.005 (TBR)	2.235 +/- 0.01	2.285 +/- 0.01
LWIR	7	11.2 (893 cm ⁻¹)	0.8 (64 cm ⁻¹)	+/- 0.05 (TBR) (+/- 40 cm ⁻¹)	10.8 +/- 0.1 (925 +/- 8 cm ⁻¹)	11.6 +/- 0.1 (861 +/- 8 cm ⁻¹)
LWIR	7	12.3 (813 cm ⁻¹)	1.0 (60 cm ⁻¹)	+/- 0.05 (TBR) (+/- 40 cm ⁻¹)	11.8 +/- 0.1 (846 +/- 8 cm ⁻¹)	12.8 +/- 0.1 (780 +/- 8 cm ⁻¹)

3.2.2.3.1 On-Board Spectral Compression

Each HES sensor **shall** downlink the equivalent of the THRESHOLD channel set, or a channel set that meets the equivalent of the threshold channel set spectral requirements and exceeds that number of channels by no more than 10% (TBR), upon ground command, excluding missing channels due to planned band breaks (see section 3.2.2.7). These channels must meet all of the PORD requirements of the THRESHOLD channel set.

Discussion: The equivalent of the threshold channel set implies that the downlink data can be delivered in radiance space or in frequency space.

3.2.2.4 Spectral Response

3.2.2.4.1 Out of Channel Response

For the CW task, the out-of-channel response is defined in Equation 3.2.2 as one minus the integrated response between the 1% response points divided by the integrated response from 0.3 microns to 20 microns. The 1% response point is defined as 1% of the peak spectral response of the system.

For the CW task, the out-of-channel response **shall** be less than 1% of the total signal when viewing either a 300 K blackbody (for channel wavelengths greater than 3 microns) or a 110% albedo scene above the atmosphere assuming no attenuation.

For the HES-CW task, the 1% response points **shall** each lie within 1.5 (TBR) times the spectral resolution element width from 50% response point.

The integrated response in the region the 50% point and the 1% point shall be less than TBD percent of the integrated response from 0.3 microns to 20 microns.

$$1 - \left(\frac{\int_{-I_{1\%}}^{+I_{1\%}} N(I)R(I)dI}{\int_{I_{0.3 \mu m}}^{I_{20 \mu m}} N(I)R(I)dI} \right) \leq 0.01 \quad \text{where}$$

$N(I)$ = 300 K blackbody or 100% albedo and

$R(I)$ is the channel relative spectral response

Equation 3.2.2 Out-of-Channel Response

3.2.2.5 Spectral Purity

For the sounding tasks, the integrated absolute value of the spectral response from outside the channel of interest **shall** be less than 28% (TBR) of the total spectral response in the channel for a uniformly illuminated aperture.

3.2.2.6 Spectral Knowledge and Stability

For the sounding tasks, the knowledge of spectral stability of the channel center of 1 part in 10^5 (TBR) or better (smaller) over TBS time at the specified wavenumbers (TBS) and wavelengths (TBS) is required.

Channel center stability **shall** be 3 parts in 10^5 (TBR) over TBS time.

Discussion: This level of performance is estimated to be required for good retrieval performance. The technical difficulty in maintaining this value must be assessed.

3.2.2.7 Spectral Band Breaks

Discussion: This section presents the limits on planned spectral band breaks due to the need to separate a band over multiple focal plane arrays. Unlike inoperable spectral channels (see section 3.2.7.2.1), which are due to random unforeseen or uncontrollable circumstances in the sensor due to, e.g., detector or electronics outages, missing channels from band breaks will always be present in all pixels. The requirements below present planned band break specifications in terms of the number of missing channels allowed in a break and the number of breaks allowed anywhere within the spectral sub-region.

All spectral band breaks must be submitted to the government for approval.

The sounding sensor(s) spectral band breaks **shall** conform to the THRESHOLD limits presented in a Table 3.2.9. Figure 3.2.4 shows a graphical representation of the sub-regions for the sounding task sensor(s).

Table 3.2.9 Sounding sensors(s) spectral band breaks THRESHOLD requirements.

Band	Sub-Region	Spectral Range (cm ⁻¹)	Band Break Limits	
			Contiguous Missing Threshold Channels per breaks	Breaks
LWIR [Band-1]	1	650-665	< or =5	< or = 2
	2	665-672	NONE	-
	3	672-722	NONE	-
	4	722-930	< or =35	< or = 3
	5	930-960	< or =35	< or = 2
	6	960-1080	< or = 5	< or = 2
	7	1080-1200	< or = 35	< or = 2
MWIR (option 1) [Band-2]	NA	1650-2150	< or = 35	< or = 5
MWIR (option 2) [Band-2]	NA	1210-1740	< or = 35	< or = 6
SWIR [Band-3]	1	2150-2230	< or = 20	1
	2	2230-2380	< or = 5	< or = 2
	3	2380-2390	NONE	-
	4	2390-2570	< or =35	< or = 2
	5	2570-2720	< or =5	< or = 2

The sounding sensor(s) spectral band breaks should conform to the GOAL limits presented in Table 3.2.10. Figure 3.2.4 shows a graphical representation of the sub-regions for the sounding task sensor(s).

Table 3.2.10 Sounding sensor(s) spectral band breaks GOAL requirements.

Band	Sub-Region	Spectral Range (cm ⁻¹)	Band Break Limits	
			Contiguous Missing Channels per breaks	Breaks
LWIR [Band-1]	1	650-665	< or = 5	1
	2	665-672	NONE	-
	3	672-722	NONE	-
	4	722-930	< or = 35	1
	5	930-960	< or = 35	1
	6	960-1080	< or = 5	1
	7	1080-1200	< or = 35	1
MWIR (option 1) [Band-2]	NA	1650-2150	< or = 35	1
MWIR (option 2) [Band-2]	NA	1210-1740	< or = 35	1
SWIR [Band-3]	1	2150-2230	< or = 20	1
	2	2230-2380	< or = 5	1
	3	2380-2390	NONE	-
	4	2390-2570	< or = 35	1
	5	2570-2720	< or = 5	1

The CW task sensor contiguous band implementation (a GOAL requirement) **shall** have fewer than two (2) band breaks.

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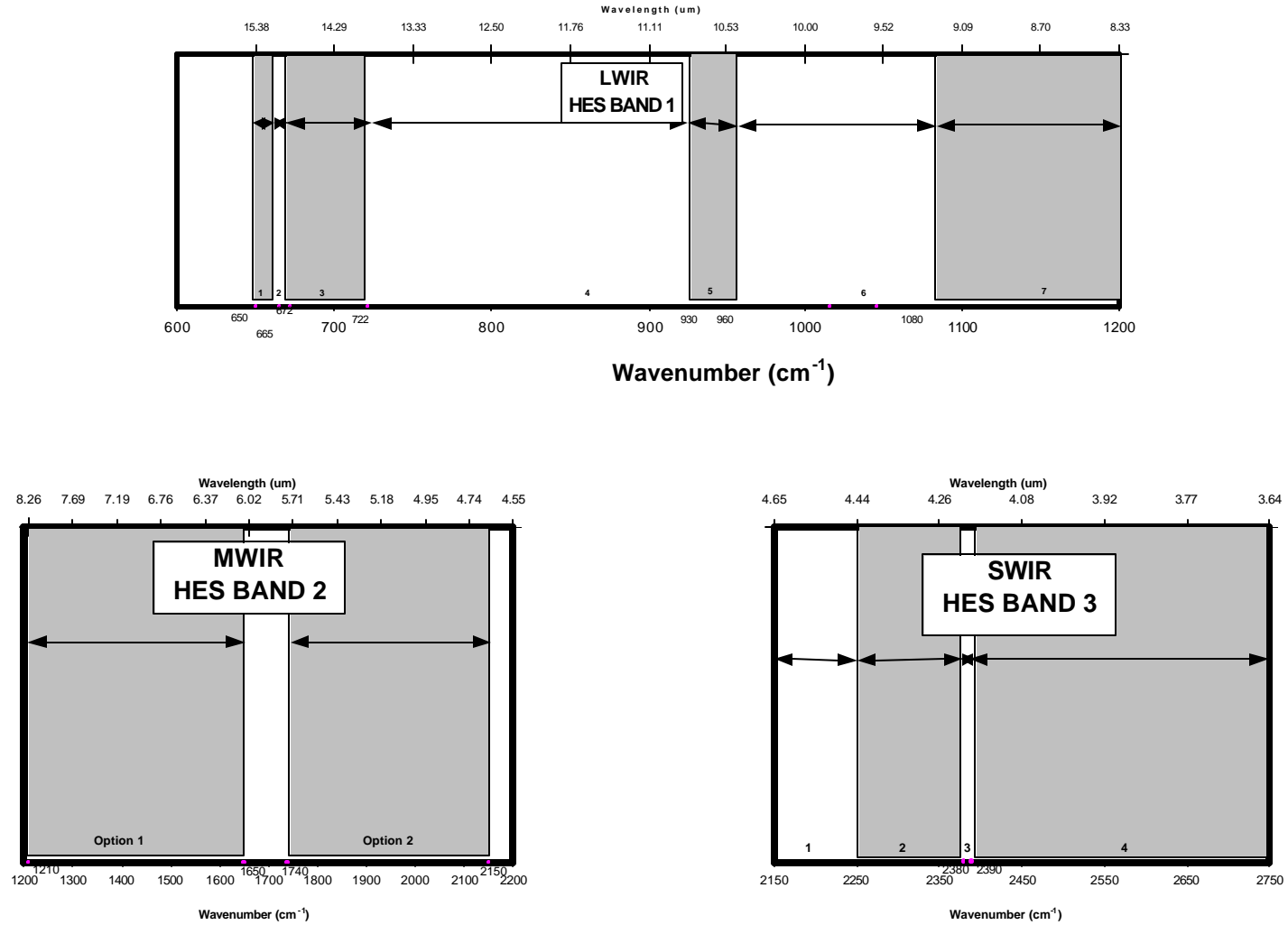


Figure 3.2.4 Graphical representation of sounding band sub-regions.

3.2.3 Scan Requirements

3.2.3.1 Ground Sample Rate

The GSR requirement **shall** be achieved for each operational task, in any data collection mode. The requirement varies by band.

The HES GSR **shall** be greater than or equal to the THRESHOLD values presented in Table 3.2.11. It should be greater than or equal to the GOAL values.

Discussion: The ground sample rate (GSR) is the number of calibrated and navigated full-spectrum pixels that will be collected per unit time. Note the GSR requirements presented below are the processed rates, and not the raw spatial sample collection rates, which are higher because of inefficiencies due to image rotation, slew time, and other overhead.

Table 3.2.11 HES THRESHOLD and GOAL GSR.

HES Band Number	Band/Task	GSR THRESHOLD (Hz)	GSR GOAL
1	LWIR-DS	195 (TBR)	$27200 / (\text{GSD})^2$
1	LWIR-SW/M	240 (TBR)	$8440 / (\text{GSD})^2$
2	MWIR-DS	195 (TBR)	$27200 / (\text{GSD})^2$
2	MWIR- SW/M	240 (TBR)	$8440 / (\text{GSD})^2$
3	SWIR- DS	195 (TBR)	$27200 / (\text{GSD})^2$
3	SWIR- SW/M	240 (TBR)	$8440 / (\text{GSD})^2$
4	VIS-DS	19,500 (TBR)	$27200 / (\text{GSD})^2$
4	VIS-SW/M	3,840 (TBR)	$8440 / (\text{GSD})^2$
5	Reflected Solar < 1 um - CW	2467 (TBR)	$666 / (\text{GSD})^2$
6	Reflected Solar > 1 um - CW	154 (TBR)	$666 / (\text{GSD})^2$
7	LWIR - CW	56 (TBR)	$666 / (\text{GSD})^2$

We anticipate that the raw GSR will be about the same for either the DS or SW/M sounding task due to differences in scan efficiency for each associated primary scan modes.

3.2.3.2 Scan Direction

The dominant direction of instrument "scan" **shall** be in the East-West directions for the DS and SW/M tasks. There is no dominant direction of scan for the CW task. To accommodate a possible seasonal yaw flip, "scanning" and stepping **shall** be possible in North to South, South to North, West to East, and East to West directions. Ground sample data acquisition should begin with the northernmost coordinate and proceed south.

3.2.3.3 Flexible and Selectable Scan Pattern

Any and all area scans **shall** be flexible and selectable.

The HES sensor(s) **shall** scan an area of arbitrary size anywhere within the full disk (described in section 3.2.4.1) when commanded. For the sounding, this area ranges from a Mesoscale region (described in section 3.2.4.4) through the size of the full disk, in integer multiples of the effective pixel array size. For the CW task, this area is no smaller than 400 km x 400 km and ranges through at least the CW coverage region, with areas in integer multiples of the effective pixel array size.

Discussion: The effective pixel array size includes inefficiencies due to image rotation and is defined after calibration and navigation. It is unique to each design.

The scan area and geographic location **shall** be selectable from one frame to the next. More details of specific coverage regions are presented in section 3.2.4.

For the purposes of this requirements document, a frame is a collection of observations that together form a spatially contiguous data set that might be analyzed to characterize the radiation from the Earth-atmosphere system. The spatial extent of a frame is described by the coverage region specifications in section (3.2.4).

The HES **shall** be designed such that the Earth-scanning patterns are fully programmable on-orbit.

The command information listed below will be uploaded concurrently with earlier operations and activated by a single command. The complexity of the required commanding must be minimized to change coverage and reduce the impact of the Sun on data loss.

Discussion: Some examples of possible approaches may include, but are not limited to:

- *Conversion of latitude and longitude to HES scan coordinate.*
- *Command the scanning mode.*
- *Command the corner locations of the frame when applicable.*
- *Command a scan that is not orthogonal to N/S or E/W (to image a storm front).*
- *Commands to minimize the impact of the Sun on data quality and quantity.*
- *Split the Full Earth into 3 segments, two are the normal E-W width and one segment has a reduced E-W width, on the East or West side, to minimize the impact of the Sun (applies to the DS task).*

3.2.3.4 Scan Efficiency

3.2.3.4.1 Within Frame Scan Efficiency

All of the following events **shall** be considered when computing the scan efficiency within a frame.

- a) Scan the required region. The coverage region is defined for each task in section 3.2.4.
- b) Scan mirror (if present) steps, settles, and slews.
- c) Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section 3.2.5.
- d) Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
- e) Operations to meet navigation requirements.

There are no requirements on within frame scan efficiency. The expected minimum values are given below for each task to provide insight.

Discussion: The within frame scan efficiency is a metric describing the fraction of time spent collecting Earth scene measurements in one complete frame. The coverage regions presented in section 3.2.4 define a frame. Frame scans are inherently inefficient for a variety of reasons. It is expected that large area frame collection will be less efficient than small area frame collection.

Table 3.2.12 Minimum expected within frame scan efficiency.

HES Task	Within Frame Scan Efficiency
DS	0.65
SW/M	0.95
CW	0.95

3.2.3.4.2 Overall Task Efficiency

TBD

As a THRESHOLD the sounding task sensor(s) **shall** continuously acquire either a DS frame *or* an SW/M frame.

The time to switch between HES sounding tasks **shall** be 25 (TBR) seconds or less.

As a GOAL, the sounding task sensor(s) should be capable of continuously and concurrently performing both a DS frame *and* an SW/M frame.

As a THRESHOLD, the CW task sensor(s) **shall** continuously acquire CW frames.

3.2.4 Coverage Area Requirements

The HES **shall** scan all coverage areas such that the centroid to centroid distance between neighboring pixels does not exceed the required Ground Sample Angle not including diagonal neighbors of a rectangular grid (TBR) and not including pixels outages within limitations defined in section 3.2.7.2.1.

Discussion: The requirements below define the geographical regions to be covered in any particular scan mode. Each HES task has different requirements for coverage with respect to geographical region. Each task has a primary geographical scan region, but is required to perform scans of other regions for operational flexibility or back-up functionality. As a reference, the area (km²) for each region is presented in Table 3.2.13. This area is referenced to a plane that is tangent to the Earth's surface at the sub-satellite point (SSP).

A complete scan of a region defines a frame of data.

Table 3.2.13 HES geographical regions coverage area.

Coverage Region	Coverage Area (km ²)
Full Disk	10 ⁸ (TBR)
62-degree LZA	7.0x10 ⁷ (TBS)
CONUS	1.5x10 ⁷ (TBR)
Mesoscale	1,000,000 (TBR)
Coastal Waters	2.4x10 ⁶ (TBR)

3.2.4.1 Full Disk Region

The full disk region is defined as a 17.76-degree diameter circle centered at nadir, as seen from each satellite. Figure 3.2.5 shows the approximate full disk coverage regions as seen from east and west satellite positions.

As a THRESHOLD, the HES sensor(s) **shall** acquire a full disk frame(s) when commanded.

Discussion: It is realized that acceptable soundings may not be retrieved over the entire full disk region. The full disk region is not a primary scan mode for any of the HES THRESHOLD tasks.

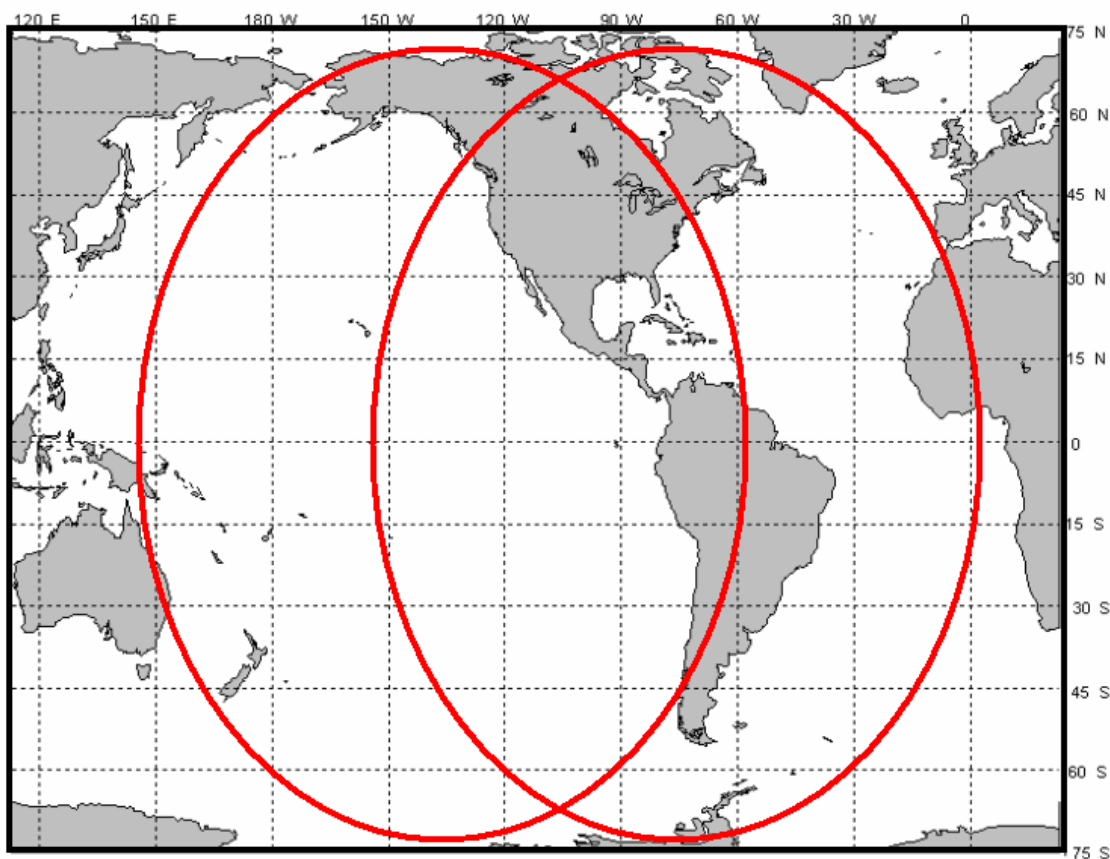


Figure 3.2.5 Approximate full disk coverage regions as seen from east and west satellite positions.

3.2.4.2 62-degree LZA Region

This region is defined as the 62-degree local zenith angle (LZA) minus half of the region of overlap that occurs between the east and west satellites. The area is shown graphically for the east and west satellites in Figure 3.2.6. The 62-degree LZA region is the primary scan mode for the DS task sensor.

As a THRESHOLD, the HES sounder task sensor(s) **shall** acquire 62-degree LZA frame(s) when commanded.

Discussion: Acceptable soundings can be retrieved over the entire region when the satellite is positioned over the equator.

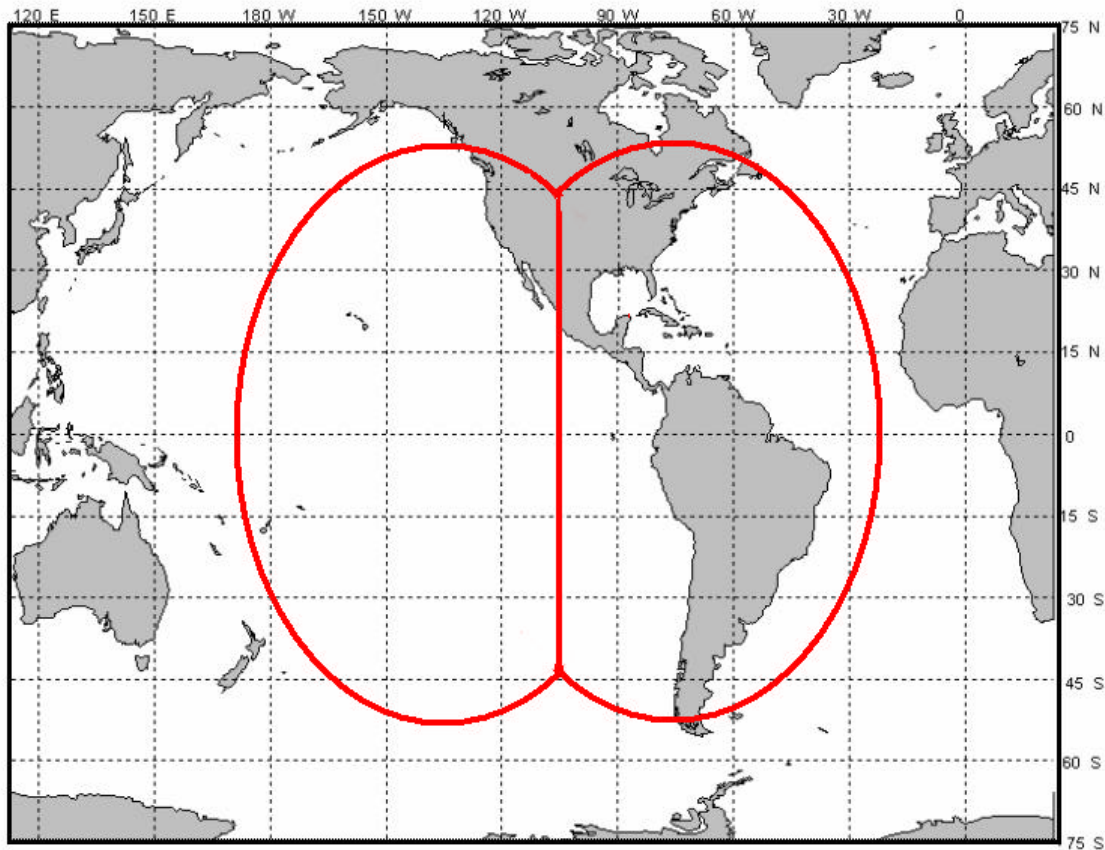


Figure 3.2.6 Approximate 62-degree LZA coverage regions as seen from east and west satellite positions.

3.2.4.3 CONUS Region

The CONUS (CONTinental UNited STates) region is defined for HES as a rectangle, 8.0215 x 4.8129 degrees (~3000-km by 5000-km). The approximate geographic area for the east satellite is 25N-50N latitude (TBR) and 50W-105W longitude (TBR). The approximate geographic area for the west satellite is 25N-50N latitude (TBR) and 105W-160W longitude (TBR).

As a THRESHOLD, the HES sensor(s) **shall** acquire CONUS-sized frame(s) when commanded.

Discussion: Acceptable soundings can be retrieved over the portion of the region falling within 62-degree LZA when the satellite is positioned over the equator. Between the east and west satellites, sounding coverage of nearly the entire CONUS region is possible. The CONUS region is not a primary scan mode for

any of the HES THRESHOLD tasks, however it is an important region and may be utilized often operationally.

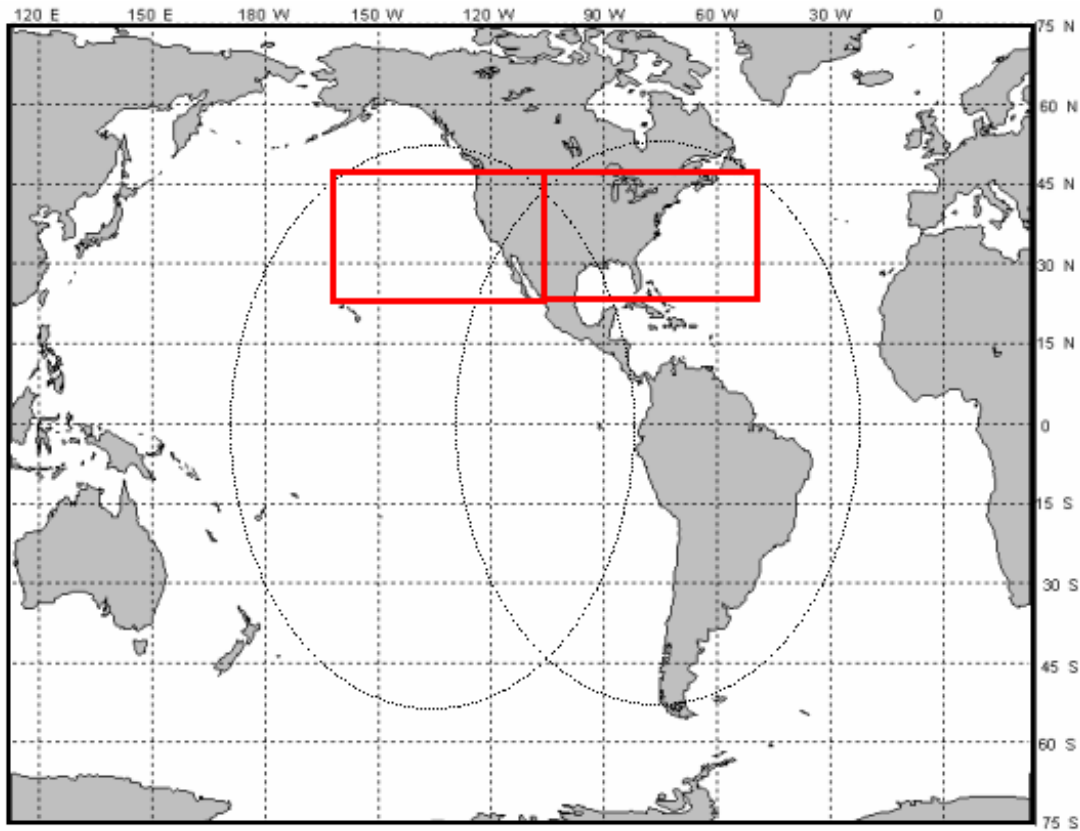


Figure 3.2.7 Approximate CONUS coverage regions as seen from east and west satellite positions, shown with 62-degree LZA limits.

3.2.4.4 Mesoscale Region

A mesoscale region is defined as a rectangular region of arbitrary size up to the equivalent of a 1.6043-degree by 1.6043-degree (~1000-km by 1000-km) nadir-viewed area. The coverage rate applies to the 1000-km by 1000-km region. Figure 3.2.8 shows several mesoscale regions from each satellite within the full disk envelope.

As a THRESHOLD, the HES sensor(s) **shall** acquire mesoscale frame(s) when commanded.

Discussion: A mesoscale region can be defined anywhere within the full disk with the understanding that acceptable soundings may only be retrieved over the 62-degree LZA region (with the satellite positioned over the equator). The mesoscale region is the primary scan mode for the SW/M task sensor.

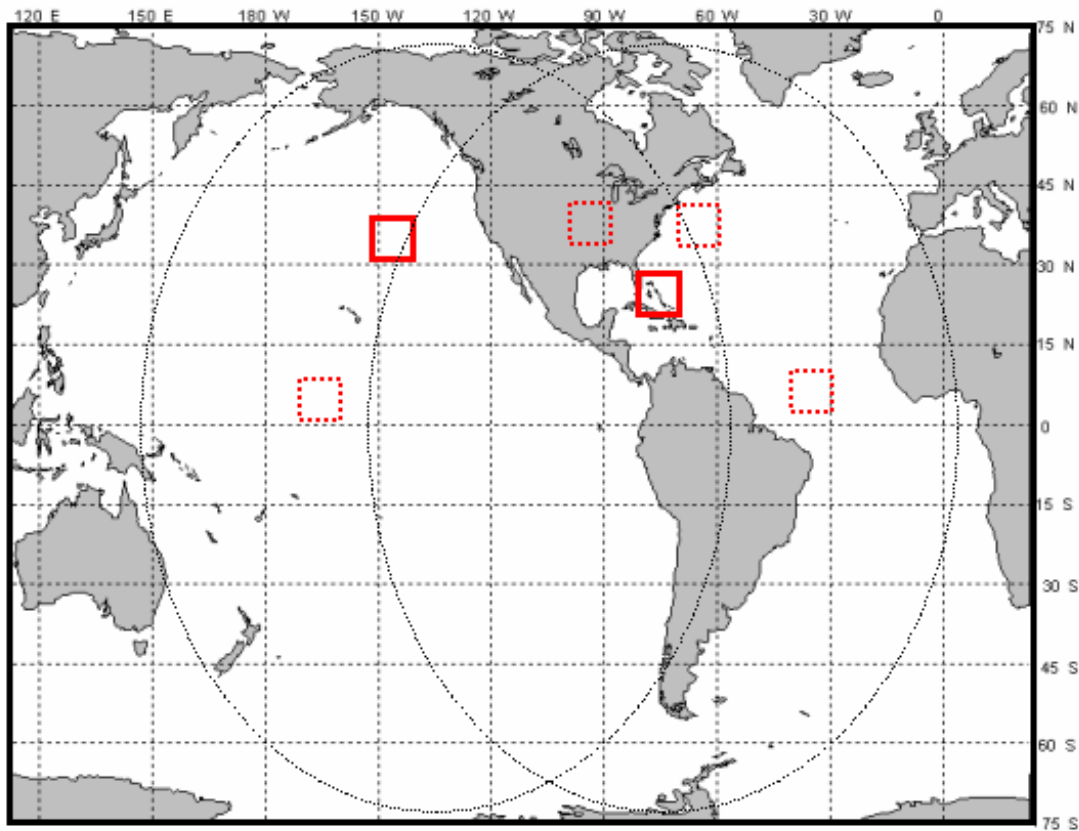


Figure 3.2.8 Mesoscale coverage regions (one east and one west), shown with full disk limits.

3.2.4.5 Coastal Waters Region

The coastal waters region addresses the US navigable waterways. For the coasts, this is defined as ocean waters within 400 km from the shore along the length of the US coast (east and gulf coast: ~6000 km, west coast: ~2100 km). Figure 3.2.9 shows the approximate coverage region for the east, gulf, and west coast of the United States.

As a THRESHOLD, the HES CW task sensor **shall** acquire coastal waters frame(s) when commanded.

Discussion: The coastal waters region is the primary scan mode for the CW task sensor however, the sensor may also be used to image lakes, rivers, and estuaries. Also note that the coverage area requirements of the CW task sensor are driven by the need for a single sensor to scan the east and gulf coasts.

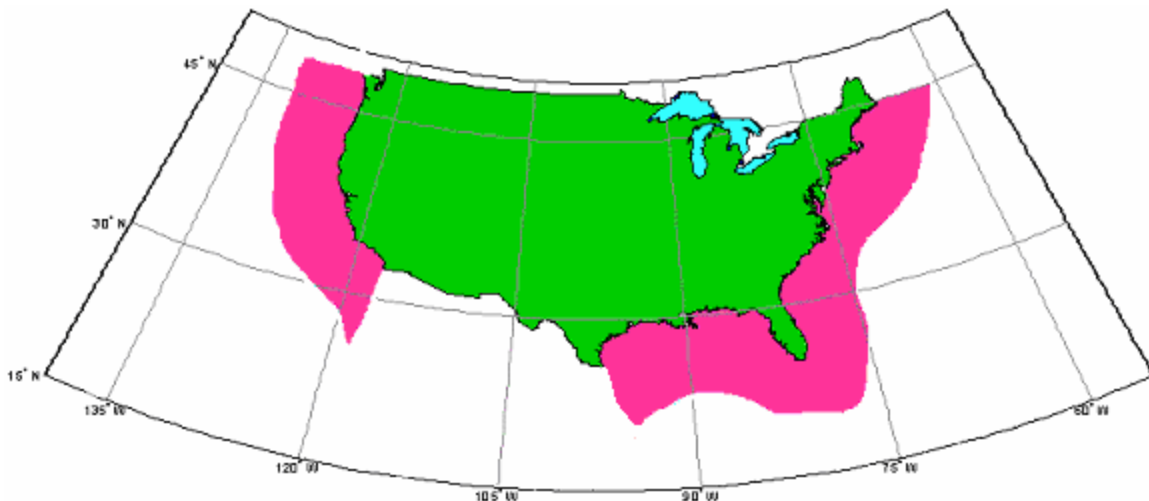


Figure 3.2.9 Approximate east and west coastal waters coverage regions (shaded pink).

3.2.4.6 CW Task Modes: Survey, Standard Localized, “570 Localized”

The survey mode is defined by the Coastal Waters Region referenced in section 3.2.4.5. This mode meets or exceeds all HES-CW task threshold requirements.

The standard localized mode provides coverage of a 400 km x 400 km area with spatially fine (approaching goal level) and spectrally fine (goal level) resolutions and approaching or exceeding goal level radiometric performance.

Discussion: Usages for the HES-CW task mode are under study, within the trade space. The usage is enveloped at one end by the survey mode and at the other end by the standard localized mode.

The survey mode **shall** be performed once during the threshold coverage time and the standard localized coverage mode should be performed TBD times during that same period.

Any CW task mode shall be invokable upon command.

As part of the study of the usage of the CW task modes, there is also a “570 localized mode” for the 0.570 um GOAL band. For this 570 localized mode, one 1200 km x 1200 km coverage region will be observed over land in CONUS in both the 0.570 um band and the 0.530 um bands during the HES-CW task period. At times of the day when no HES-CW scene is required the 570 localized mode will be used.

At times of the day when no HES-CW scene is required, there should be TBD number of 1200 km x 1200 km regions measured in one hour while meeting the required radiometric performance for one half of the “max vegetation” radiance curve supplied in appendix B.

Discussion: It is intended that the 0.570 μm land coverage must not be a system driver, but instead what can be achieved within the vendors instrument design with the addition of this band. This band will be used in combination with the 0.530 μm band only.

3.2.5 Spatial Sampling Requirements

3.2.5.1 Field of Regard

The field of regard (FOR) is defined as an angular diameter through which the instrument can detect any instrument-external source of interest. The diameter is centered at the SSP and the angle is measured at the instrument. This field of regard is unvignetted. The HES **shall** have at least a 20 degree FOR.

Discussion: The unvignetted FOR will accommodate the calibration and navigation needs (section 3.2.8) of the HES tasks being addressed by the instrument. For HES, these sources include at least space, which is used for instrument background subtraction when appropriate, and emission from the Earth's atmosphere and surface. NOAA would like to perform scans of space above and below the earth to assess the emissivity of the scan mirror.

3.2.5.2 Ground Sample Distance and Angle

The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, *as measured at the SSP*, defines the ground sample distance (GSD). A two-dimensional pixel is defined by the GSD in the East/West and North/South dimensions, therefore a single GSD quantity is specified for each task and each band required for the task.

The DS task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.14. It should produce pixels as small as the GOAL values.

Discussion: The associated ground sample angle (GSA) is constant for all scan positions and satellite altitude geometries. Often in this document, the GSD is referenced with the caveat that the actual GSD is calculated from the GSA.

Table 3.2.14 DS task sensor THRESHOLD and GOAL GSD and GSA capabilities.

Band	HES Band Number	THRESHOLD		GOAL	
		GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
LWIR	1	10	280	2	56
MWIR	2	10	280	2	56
SWIR	3	10	280	2	56
VIS	4	1	28.0	0.5	14

The SW/M task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.15. It should produce pixels as small as the GOAL values.

Table 3.2.15 SW/M task sensor THRESHOLD and GOAL GSD capabilities.

Band	HES Band Number	THRESHOLD		GOAL	
		GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
LWIR	1	4	111	2	56
MWIR	2	4	111	2	56
SWIR	3	4	111	2	56
VIS	4	1	28	0.5	14

The CW task sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table 3.2.16. It should produce pixels as small as the GOAL values.

Table 3.2.16 CW task sensor THRESHOLD and GOAL GSD capabilities.

Band	HES Band Number	THRESHOLD		GOAL	
		GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
Reflected Solar < 1 um	5	0.3 (TBR)	8.3 (TBR)	0.15 (TBR)	4.2 (TBR)
Reflected Solar > 1 um	6	1.2 (TBR)	33 (TBR)	0.9 (TBR)	25 (TBR)
LWIR	7	2	56	1	28

3.2.5.3 Pixel Spatial Binning

Upon ground command, any HES task sensor **shall** downlink pixels having the threshold GSD to within +4% (TBR) or -25% (TBR), while satisfying all other THRESHOLD requirements.

Upon ground command, any HES task sensor performing on-board spatial pixel binning **shall** downlink the unaggregated pixels. (Requirement under study: TBR).

3.2.5.4 Detector Sample Ground Footprint

Discussion: This section presents the detailed requirements of the imaged detector elements on the ground. The requirements with regard to detector sample ground footprint vary depending on task and band and on whether the function is imaging or sounding. The CW task is subject to MTF requirements (section 3.2.5.4.4), while the sounding task is subject to ensquared energy requirements (section 3.2.5.4.3). As such the requirements below are presented by task and separated by band when appropriate.

3.2.5.4.1 Geometric Shape

There is no requirement on the geometric shape of the footprint as long as all other THRESHOLD spatial sampling requirements are satisfied (TBR).

3.2.5.4.2 Spatial Response Knowledge

As a THRESHOLD, the two-dimensional spatial response per channel **shall** be known to better than TBD% of the average response by measurement. The measurement resolution **shall** be TBD.

As a GOAL, the two-dimensional spatial response per channel should be known to better than 5% (TBR) of the average response by measurement. The measurement resolution should be TBD.

3.2.5.4.3 Detector/Optics Ensquared Energy

The detector/optics ensquared energy (DOEE) is a unitless figure of merit, which is the ratio of the energy *measured by* a detector from its corresponding ground sample area (defined by the Threshold GSD (TGSD), not the detector active-area projection on the ground) to the energy *measured by* the detector from the entire large and uniform scene. The DOEE can be understood in terms of the scene-spread function (SSF), which is the convolution of the polychromatic system point-spread function (PSF) with the detector spatial response function (SRF); however, the detector spatial response function *must* be measured in order to fully characterize all of the optical and electrical cross-talking.

$$\text{DOEE} := \frac{\int_{-\frac{\text{TGSD}}{2}}^{\frac{\text{TGSD}}{2}} \int_{-\frac{\text{TGSD}}{2}}^{\frac{\text{TGSD}}{2}} \text{SSF} dx}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \text{SSF} dx dy}.$$

Equation 3.2.2

Figure 3.2.10 is a 1-D graphical representation of the above equation.

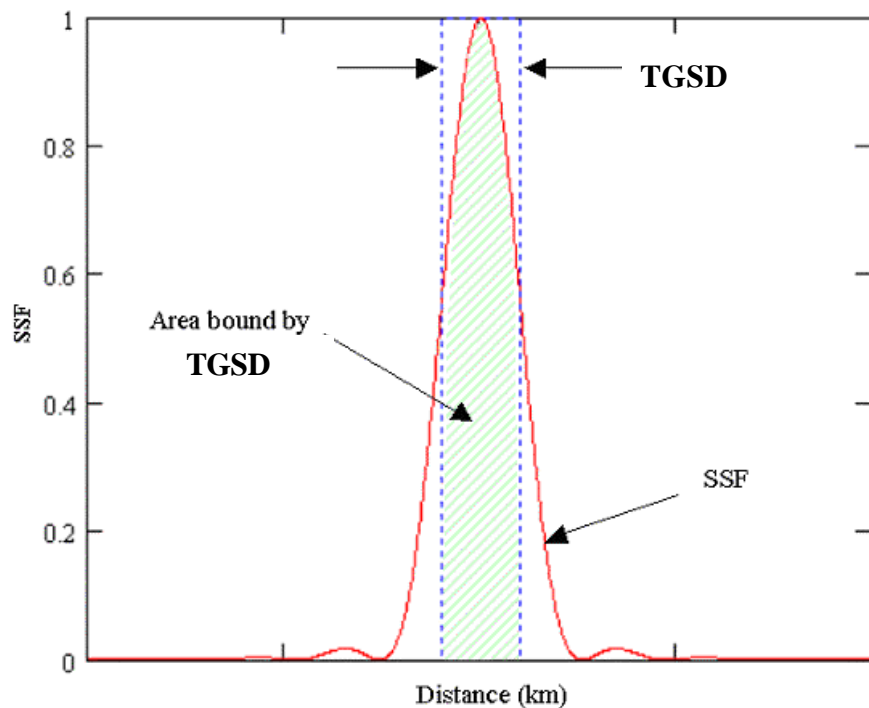


Figure 3.2.10 1-D graphical representation of Equation 3.2.2.

As a standard, the DOEE *is always* referenced to the TGSD. The DOEE requirements below are presented by band. The requirement applies to all channels within each specified band.

The DS task sensor DOEE **shall** be greater than or equal to the THRESHOLD requirements presented in Table 3.2.17.

The DS task sensor DOEE should be greater than or equal to the GOAL requirements.

The Reflected Solar band (HES band 4) is not subject to this requirement.

Discussion: Optical and electrical cross-talking is present in real detectors. This adds to the wings of the detector spatial response and degrades the DOEE.

Table 3.2.17 DS task sensor THRESHOLD and GOAL DOEE requirements.

Band	HES Band Number	DOEE (%) THRESHOLD	DOEE (%) GOAL
LWIR	1	90 (TBS)	93
MWIR	2	90 (TBS)	93
SWIR	3	90 (TBS)	93

The SW/M task sensor DOEE **shall** be greater than or equal to the THRESHOLD requirements presented in Table 3.2.18.

The DS task sensor DOEE should be greater than or equal to the GOAL requirements.

The Reflected Solar band (HES band 4) is not subject to this requirement.

Pixel to pixel cross-talk in the HES emissive bands (HES bands 1-3, and 7) will be low enough to meet ensquared energy requirements.

Table 3.2.18 SW/M task sensor THRESHOLD and GOAL DOEE requirements.

Band	HES Band Number	DOEE (%) THRESHOLD	DOEE (%) GOAL
LWIR	1	64	90
MWIR	2	64	90
SWIR	3	64	90

3.2.5.4.4 Modulation Transfer Function

The spatial resolution of the HES imaging bands is defined by the system modulation transfer function (MTF). The sensor(s) **shall** meet the requirements below in both East/West and North/South directions after any ground processing including spacecraft jitter as detailed in the HES IRD.

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) **shall** meet the MTF requirements listed in Table 3.2.19.

Discussion: The values are consistent with 1.0 km resolution in this band.

Table 3.2.19 Sounding task sensor(s) Reflected Solar band MTF requirement.

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
8.0	4500	0.85 (TBR)
4.0	9000	0.73 (TBR)
2.666	13500	0.53 (TBR)
2.0	18000	0.32 (TBR)

As a THRESHOLD, the CW task sensor Reflected Solar < 1 um band (HES band 5) **shall** meet the MTF requirements listed before the gap in Table 3.2.20. As a GOAL, the CW task sensor Reflected Solar < 1 um band (HES band 5) should meet the MTF requirements listed after the gap in Table 3.2.20. Note the MTF varies with the spatial sampling.

Discussion: The set of values before the table gap are consistent with 0.3 km resolution in this band (TBR) and the set of values after the table gap are consistent with 0.15 km resolution in this band (TBR).

Table 3.2.20 CW task sensor Reflected Solar < 1 um band MTF requirement

Spatial Frequency (T)		System MTF (T)
(km/cyc)	(cyc/rad)	
2.4	15000	0.90 (TBR)
1.2	30000	0.73 (TBR)
0.8	45000	0.53 (TBR)
0.6	60000	0.32 (TBR)
Spatial Frequency (G)		System MTF (G)
(km/cyc)	(cyc/rad)	
1.2	30000	0.90 (TBR)
0.6	60000	0.73 (TBR)
0.4	90000	0.53 (TBR)
0.3	120000	0.32 (TBR)

As a THRESHOLD, the CW task sensor Reflected Solar > 1 um band (HES band 6) **shall** meet the MTF requirements listed in Table 3.2.21. As a GOAL, the CW task sensor Reflected Solar > 1 um band (HES band 6) should meet the MTF requirements listed after the gap in Table 3.2.21. Note the MTF varies with the spatial sampling.

Discussion: The set of values before the table gap are consistent with 1.2 km resolution in this band (TBR) and the set of values after the table gap are consistent with 0.9 km resolution in this band (TBR).

Table 3.2.21 CW task sensor Reflected Solar > 1 um band MTF requirement.

Spatial Frequency (T)		System MTF (T)
(km/cyc)	(cyc/rad)	
9.6	3750	0.90 (TBR)
4.8	7500	0.73 (TBR)
3.2	11250	0.53 (TBR)
2.4	15000	0.32 (TBR)
Spatial Frequency (G)		System MTF (G)
(km/cyc)	(cyc/rad)	
7.2	5000	0.90 (TBR)
3.6	10000	0.73 (TBR)
2.4	15000	0.53 (TBR)
1.8	20000	0.32 (TBR)

As a THRESHOLD, the CW task sensor LWIR band (HES band 6) **shall** meet the MTF requirements listed in Table 3.2.22.

Discussion: The values are consistent with 2 km resolution in this band. (TBR).

Table 3.2.22 CW task sensor LWIR band MTF requirement.

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
16.0	2250	0.84
8.0	4500	0.62
5.33	6750	0.39
4.0	9000	0.22

Pixel to pixel cross-talk in the HES reflective bands (HES bands 4-6) will be low enough to meet MTF requirements.

3.2.5.5 Co-registration

Channel-to-channel registration error, or co-registration, is the difference in pointing between spectral channels for any given pixel in the same frame.

The requirements below specify how well the HES bands must be registered to each other. The requirements only apply to channels within a single sensor task (DS, SW/M, CW and OO). Co-registration between channels having different GSD is defined by centroiding a grid of the finer pixels to determine a “mean” pixel equal in extent to the coarser pixel.

As a THRESHOLD, the centroid channel-to-channel registration error between bands in the sounding task sensor(s) **shall** not exceed the values presented in Table 3.2.23. Values for emissive bands (HES bands 1-3) are written in terms of a percentage of the ground sample angle (GSA). Values for the reflective band (HES band 4) are written as an absolute angle.

Table 3.2.23 Sounding task sensor(s) co-registration THRESHOLD requirements.

	LWIR	MWIR	SWIR	Reflected Solar
LWIR	0.1 GSA (TBR)	0.1 GSA (TBR)	0.1 GSA (TBR)	52.5 urad (TBR)
MWIR		0.1 GSA (TBR)	0.1 GSA (TBR)	52.5 urad (TBR)
SWIR			0.1 GSA (TBR)	52.5 urad (TBR)
VIS				52.5 urad (TBR)

Discussion: Since the sounding process involves the combination of data from each of the individual spectral channels, it is vital that the energy detected in each spectral channel from the sounding task sensor(s) emanate from the same column of air as closely as possible. In a similar fashion, the CW task sensor will require the same geographic coverage of the various spectral bands because products involving multiple bands will be formed. This becomes especially important in regions of strong gradients.

As a THRESHOLD, the centroid co-registration errors in the CW task sensor **shall** not exceed the values presented in Table 3.2.24. Values are written as an absolute angle.

Table 3.2.24 CW task sensor co-registration THRESHOLD requirements.

	Reflected Solar < 1 um	Reflected Solar > 1 um	LWIR
Reflected Solar < 1 um	6.75 urad (TBR)	6.75 urad (TBR)	10.5 urad (TBR)
Reflected Solar > 1 um		6.75 urad (TBR)	10.5 urad (TBR)
LWIR			10.5 urad (TBR)

As a GOAL, the centroid co-registration errors in the CW task sensor should not exceed the values presented in Table 3.2.25. Values are written as an absolute angle.

Table 3.2.25 CW task sensor co-registration GOAL requirements.

	Reflected Solar < 1 μm	Reflected Solar > 1 μm	LWIR
Reflected Solar < 1 μm	2.25 urad	2.25 urad	2.25 urad
Reflected Solar > 1 μm		2.25 urad	2.25 urad
LWIR			2.25 urad

3.2.6 Temporal Requirements

3.2.6.1 Coverage Time

The coverage time for each region is defined as the time to produce a complete frame of data. It is specified for each of the primary scan regions for each sensor task. All of the following **shall** be performed within the coverage time:

- Scan the required region. The coverage region is defined for each task in section 3.2.4.
- Scan mirror (if present) steps, settles, and slews.
- Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section 3.2.5.
- Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
- Necessary operations to switch between tasks if one sensor is used for multiple tasks.
- Operations to meet navigation requirements.

As a THRESHOLD the DS task sensor **shall** scan the 62-degree LZA region in 1 hour when commanded.

As a GOAL, the DS task sensor should scan the Full Disk region in 1 hour when commanded.

As a THRESHOLD the SW/M task sensor **shall** scan the mesoscale region in 4.4 minutes when commanded.

As a GOAL the SW/M task sensor should scan the mesoscale region in 2 minutes (TBR) when commanded.

As a THRESHOLD the CW task sensor **shall** scan the coastal waters region in 3 hours when commanded.

As a GOAL the CW task sensor should scan the coastal waters region in 1 hour (TBR) when commanded.

Discussion: In general, the maximum expected scan time for each task will increase with an increase in coverage area. This simply reflects that the GSR is a rate, based on a product pixel sample so that the inverse of the product of the GSR will be the coverage area. Employing 10 km spatial resolution and the threshold DS GSR yields a one hour coverage time for the 62 degree LZA spatial region, a one hour thirty-three minute coverage time for the Full Disk, and just over 9 minutes for a CONUS sized area. Employing a 4 km spatial resolution and the threshold DS GSR yields a coverage time of just over one hour for the CONUS region.

3.2.6.2 Spectral Bands Simultaneity

As a THRESHOLD, data from spectral bands 1-4 of HES obtained from any specific point on the Earth **shall** be coincident within 10 seconds.

As a GOAL, data from spectral bands 1-4 of HES obtained from any specific point on the Earth **shall** be coincident within 5 seconds.

As a THRESHOLD, data from spectral bands 5-7 of HES obtained from any specific point on the Earth **shall** be coincident within 15 seconds.

As a GOAL, data from spectral bands 5-7 of HES obtained from any specific point on the Earth **shall** be coincident within 10 seconds.

3.2.6.3 Adjacent Pixels Simultaneity

The time between collection of adjacent pixels within a single HES data frame **shall** be less than or equal to the THRESHOLD values presented in Table 3.2.26.

The time between collection of adjacent pixels within a single HES data frame should be less than or equal to the GOAL values.

Table 3.2.26 THRESHOLD and GOAL pixel simultaneity requirements.

Sounding Task Sensor(s)			CW Task Sensor	
Coverage Region	Pixel Simultaneity THRESHOLD	Pixel Simultaneity GOAL	Pixel Simultaneity THRESHOLD	Pixel Simultaneity GOAL
Full Disk	TBD	TBD	TBD	TBD
62-degree LZA	6 min	3 min	TBD	TBD
CONUS	3 min	2 min	TBD	TBD
Mesoscale	4.4 min	TBD	TBD	TBD
Coastal Waters	TBD	TBD	10 min (TBR)	TBD

Discussion: Temporal simultaneity is important for the purpose of creating images, or using retrieval information in weather prediction models. The requirements below present the maximum time between Earth measurements for adjacent pixels. When a sensor rasters a detector footprint (or array of detector footprints) across a scene to create a complete frame, these requirements determine the maximum swath length. The requirements are presented for each HES task and for each geographical coverage region.

3.2.6.4 Time Tagging

The data **shall** be time identified so that the time any detector sample in the data was acquired can be determined to within 0.1 milliseconds relative to the spacecraft provided clock information. The spacecraft clock is synchronized to Universal Time (UT) to an accuracy defined in the GIRD.

3.2.7 Radiometric Performance Requirements

3.2.7.1 Dynamic Range

The HES bands 1 – 3 and 7 **shall** have sufficient dynamic range to measure cold space and the Earth as viewed at the temperature at maximum radiance (from appendix B).

Discussion: The HES vendor must determine the actual dynamic range to account for stray light, hot optics, maximum blackbody temperature, or any other condition that will saturate the detectors and prevent proper measurement of the required scene temperature range.

HES band 5 (Reflected solar < 1 um) in the CW task sensor **shall** have sufficient dynamic range for measurements between 0 and at least 10 (TBR) % above the “100 albedo” supplied spectrum (see appendix B) without saturation of any detector element.

Discussion: It is important to note that the 110% albedo detection does not need to be implemented on the same detector that supplies the “minimum” signal spectral data and the “maximum” signal spectral data from appendix B.

HES band 4 (Visible) and HES band 6 (Reflected Solar > 1um) **shall** have sufficient dynamic range for measurements between 0 to 110% albedo solar spectrum without saturation of any detector element.

3.2.7.2 Measurement Precision (SNR, NEdN, and NEdT)

The noise performance requirements are defined by the noise-equivalent radiance difference (NEdN) for emissive bands (HES bands 1 – 3, and 7) and signal to noise ratio (SNR) for reflective bands (HES bands 4-6). The noise radiance is defined as the standard deviation (1 sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene. The signal radiance in each case is defined as the top of the atmosphere radiance (TOA) at the aperture of the system. The NEdT at a given wavelength is defined by dividing the NEdN at that wavelength by the derivative with respect to temperature of the Planck blackbody radiance function, evaluated at 250 K at the same wavelength. The NEdN and NEdT, or SNR is defined at several key channels within a band. The requirement for channels between those identified can be found by linear interpolation in NEdN space.

Discussion: The measurement precision is a fundamental performance metric for the HES.

For data acquired at more than one sample per threshold channel, the noise performance (NEdN, NEdT, or SNR) **shall** be determined on the aggregate with a spectral bandwidth less than or equal to the threshold channel as a THRESHOLD.

As a GOAL the noise performance (NEdN, NEdT, or SNR) should be met on the individual spectral samples.

As a THRESHOLD, the sounding task sensor(s) LWIR band (HES band 1) NEdN **shall** be less than or equal to the values plotted in Figure 3.2.11. NEdT values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.12. Values for key wavelengths are quantified in Table 3.2.27.

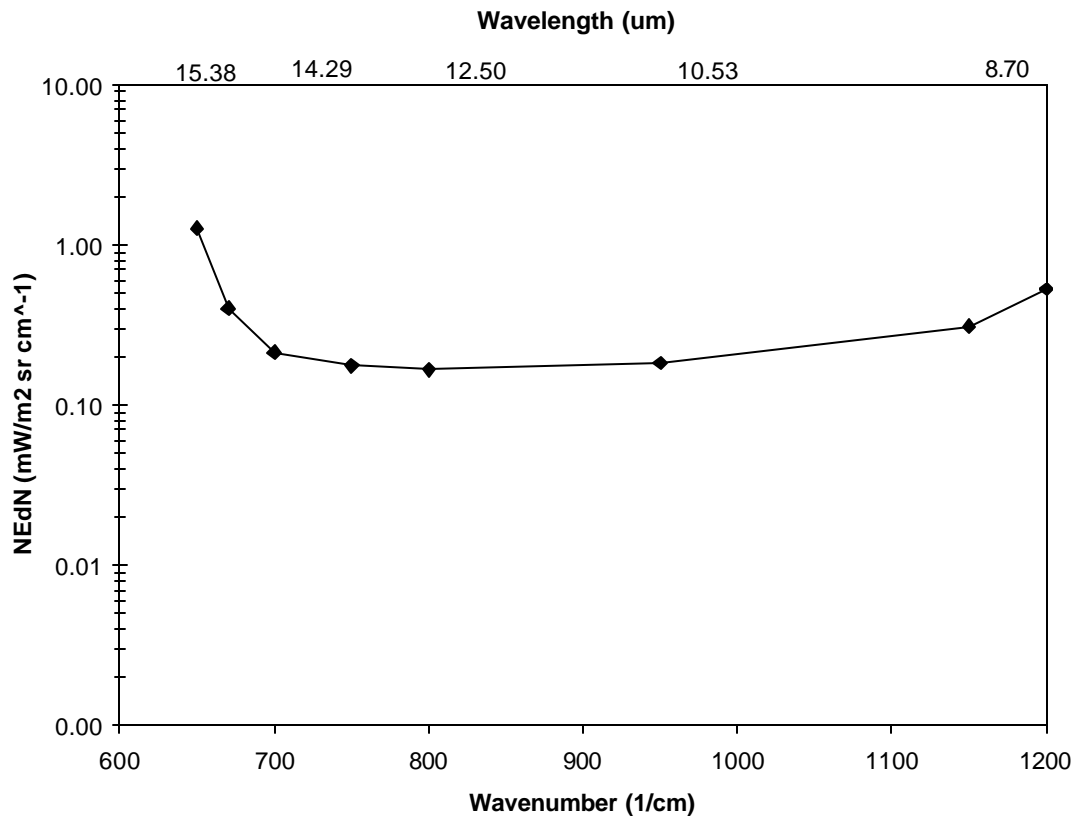


Figure 3.2.11 Plot of sounding sensor(s) LWIR NEdN requirement.

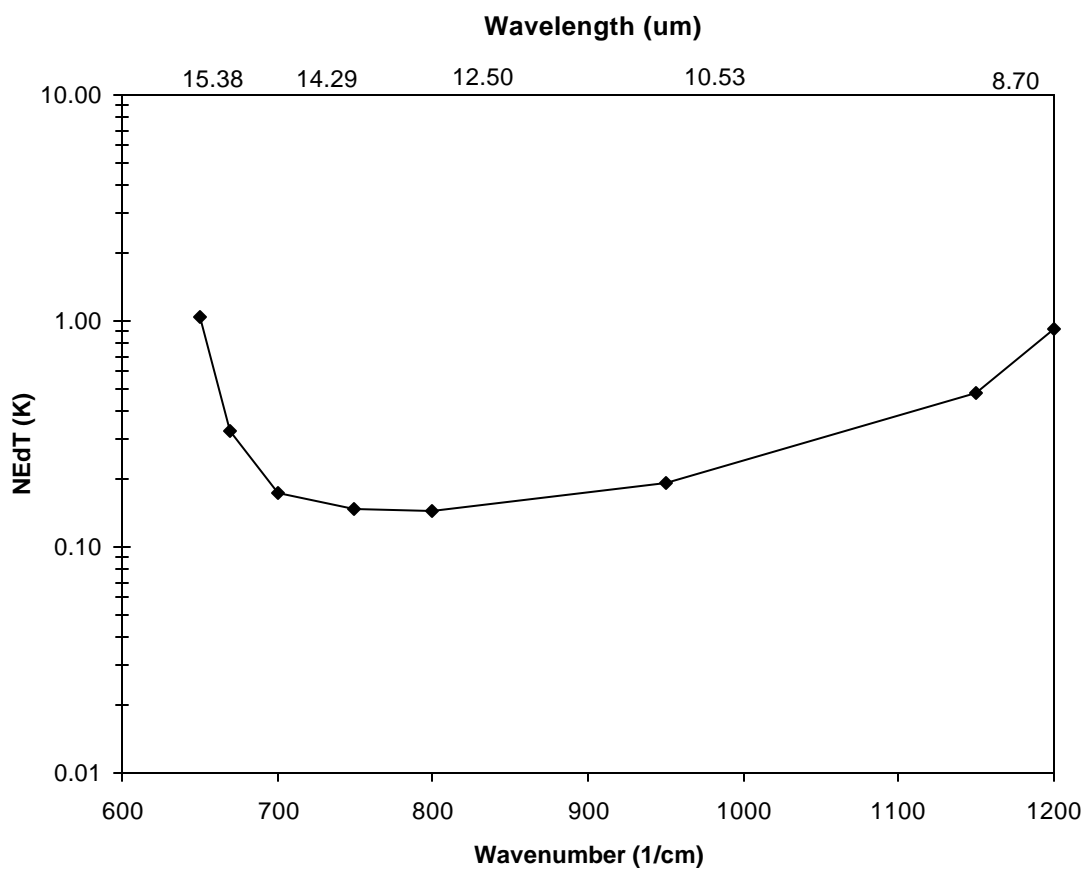


Figure 3.2.12 Plot of sounding sensor(s) LWIR NEdT @250K requirement.

Table 3.2.27 Sounding sensor(s) LWIR NEdN and NEdT requirements.

Wavenumber (cm ⁻¹)	Wavelength (um)	NEdN (mW/m ² sr cm ⁻¹)	NEdT @ 250K (K)
650	15.38	1.265	1.036
670	14.93	0.40	0.31
700	14.29	0.212	0.175
750	13.33	0.176	0.147
800	12.50	0.166	0.146
950	10.53	0.182	0.191
1150	8.70	0.310	0.483
1200	8.33	0.529	0.918

As a THRESHOLD, the sounding task sensor(s) MWIR band (HES band 2) NEdN **shall** be less than or equal to the values plotted in

Figure 3.2.13. NEdT values are calculated using 250 K as the reference temperature and plotted in

Figure 3.2.14. Values for key wavelengths are quantified in Table 3.2.28.

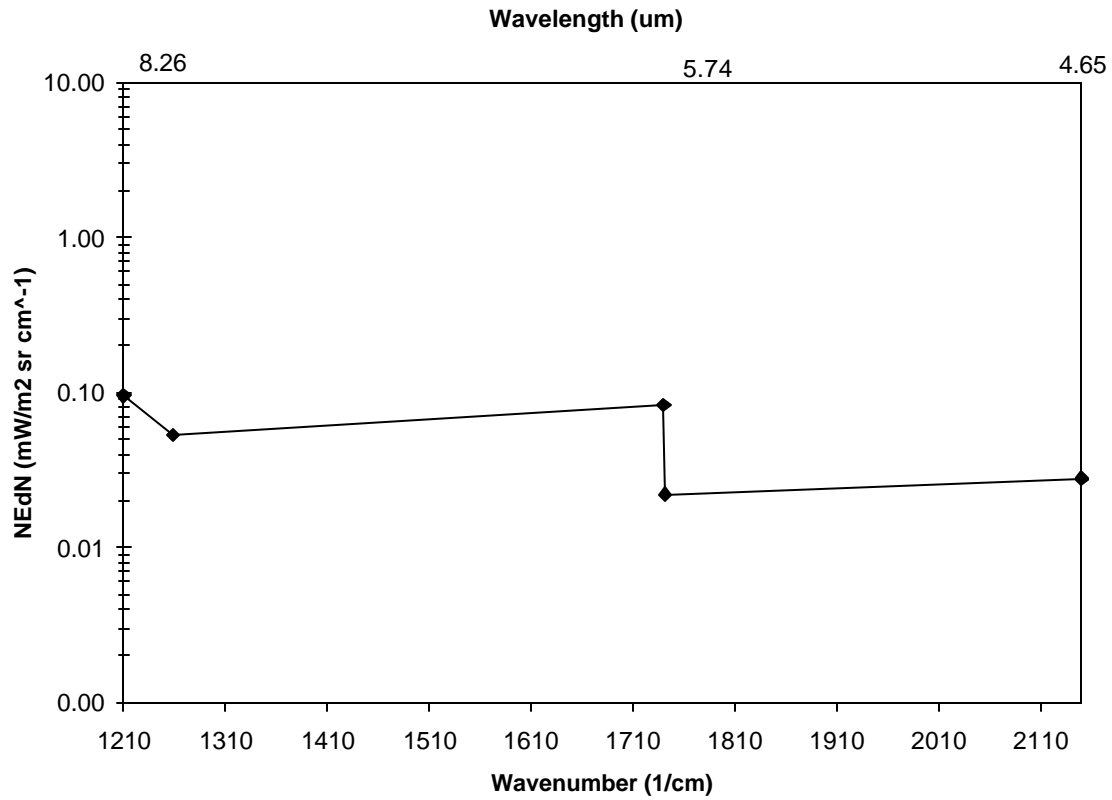


Figure 3.2.13 Plot of sounding sensor(s) MWIR NEdN requirement.

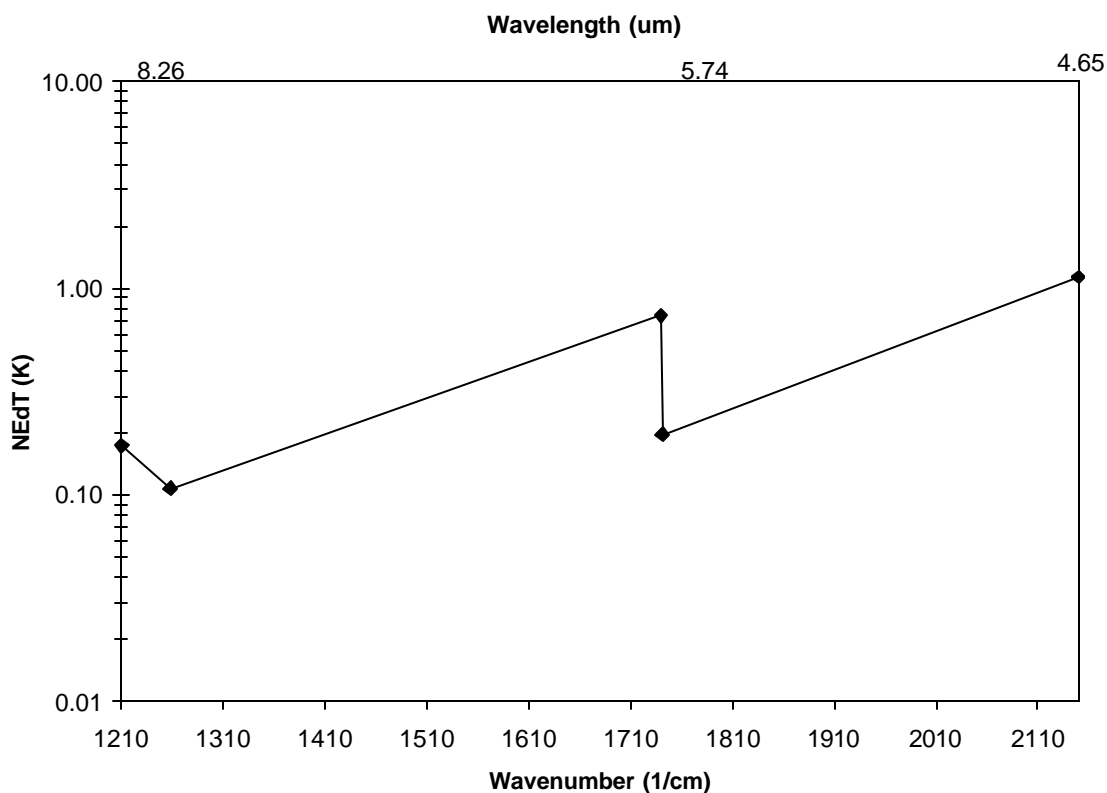


Figure 3.2.14 Plot of sounding sensor(s) MWIR NEdT @250K requirement.

Table 3.2.28 Sounding sensor(s) MWIR NEdN and NEdT requirements.

Wavenumber (cm ⁻¹)	Wavelength (um)	NEdN (mW/m ² sr cm ⁻¹)	NEdT @ 250K (K)
1210	8.26	0.096	0.24
1258	7.95	0.053	0.13
1740	5.75	0.083	0.74
1741	5.74	0.022	0.20
2150	4.65	0.028	1.57

As a THRESHOLD, the sounding task sensor(s) SWIR band (HES band 3) NEdN **shall** be less than or equal to the values plotted in Figure 3.2.15 (solid line). NEdT values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.16. Values for key wavelengths are quantified in Table 3.2.29.

As a GOAL, the sounding task sensor(s) SWIR band (HES band 3) NEdN should be less than or equal to the values plotted in

Figure 3.2.15 (dashed line). NEdT values are calculated using 250 K as the reference temperature and plotted in Figure 3.2.16. Values for key wavelengths are quantified in Table 3.2.29.

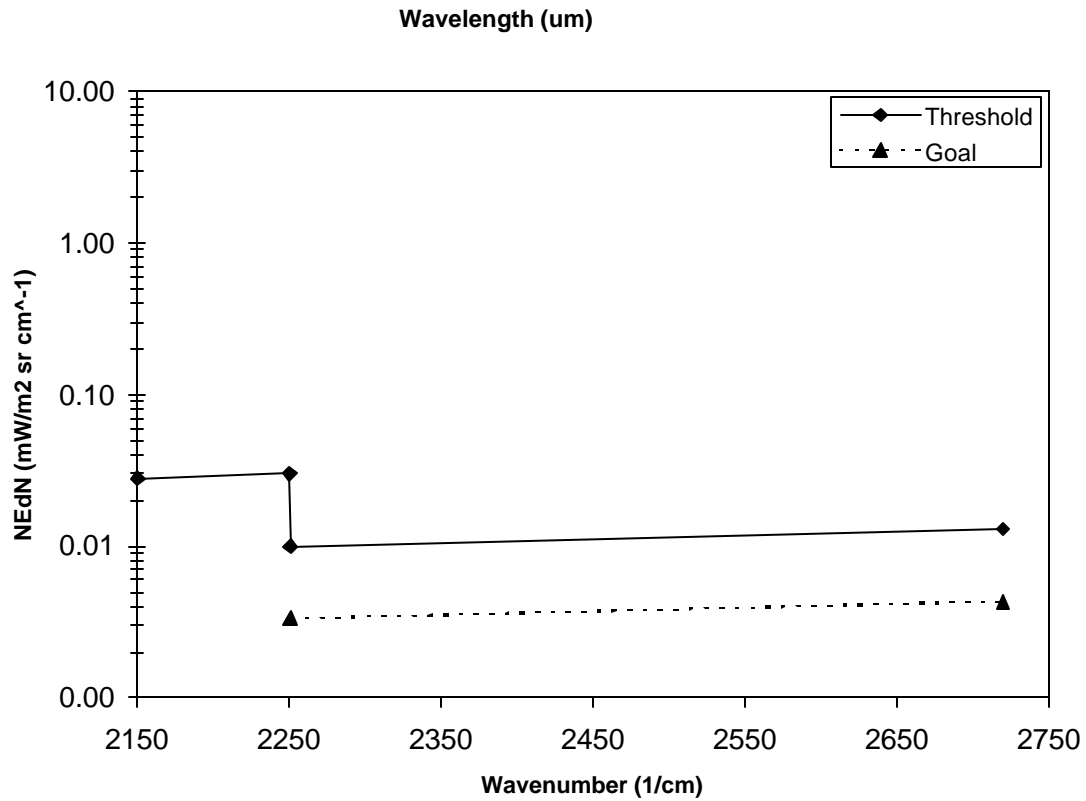


Figure 3.2.15 Plot of sounding sensor(s) SWIR NEdN requirement.

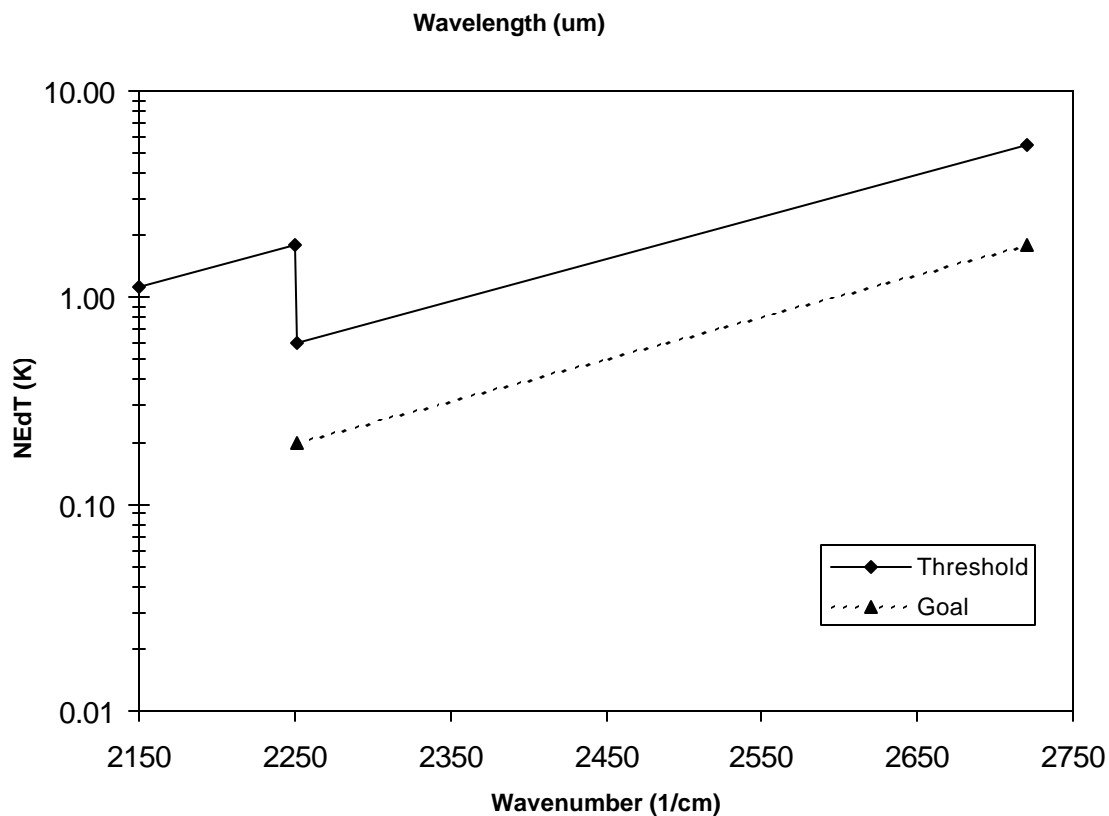


Figure 3.2.16 Plot of sounding sensor(s) SWIR NEdT @250K requirement.

Table 3.2.29 Sounding sensor(s) SWIR NEdN and NEdT requirements.

Wavenumber (cm ⁻¹)	Wavelength (um)	NEdN (mW/m ² sr cm ⁻¹)		NEdT @ 250K (K)	
		THRESHOLD	Goal	THRESHOLD	Goal
2150	4.65	0.028	NA	1.57	NA
2250	4.44	0.03	NA	2.57	NA
2251	4.44	0.010	0.003	0.6	0.2
2720	3.68	0.013	0.004	5.03	1.68

Discussion: The requirements apply for any possible clear air Earth scene spectral radiance; see section (2.10.2)3.B.2.m of the MRD and appendix B of this document for representatives of the extremes in radiance. The requirements only apply to channels present in the sensor, i.e. optional and GOAL channels not provided in the design are not subject to these requirements.

Discussion: It is recognized that for some large focal plane array implementations there could be a significant spread in performance across the

array due to the statistical nature of the detection device. The performance distribution maps to the spectral dimension in a dispersive implementation, and the spatial dimension in a multiplexing implementation. Specifications setting the bounds to the performance distribution in the spectral dimension are presented in section 3.2.7.2.1. Specifications setting the bounds to the performance distribution in the spatial dimension are presented in section 3.2.7.2.1.

As a THRESHOLD, the sounding task sensor(s) Reflected Solar band (HES band 4) SNR **shall** be greater than or equal to 300 at 110% albedo with a low light capability having a signal to noise level greater than or equal to 10 (TBR) over a 2 km sample using 5% albedo; the signal level past sunset at the ground point of interest and extending as far as possible into night conditions will be lower than this specified level. As a GOAL, the sounding task sensor(s) Reflected Solar band (HES band 4) SNR **shall** be greater than or equal to 600 at 110% albedo with at least the low light capability just described.

The CW task sensor Reflected Solar bands (HES bands 5 and 6) SNR **shall** be greater than or equal to the THRESHOLD values plotted in Figure 3.2.17 for the “Minimum” supplied radiances in appendix B, and **shall** be identified as such.

As a GOAL, the CW task sensor Reflected Solar bands (HES bands 5 and 6) SNR should be greater than or equal to the GOAL values. Values for THRESHOLD channels are in Table 3.2.30.

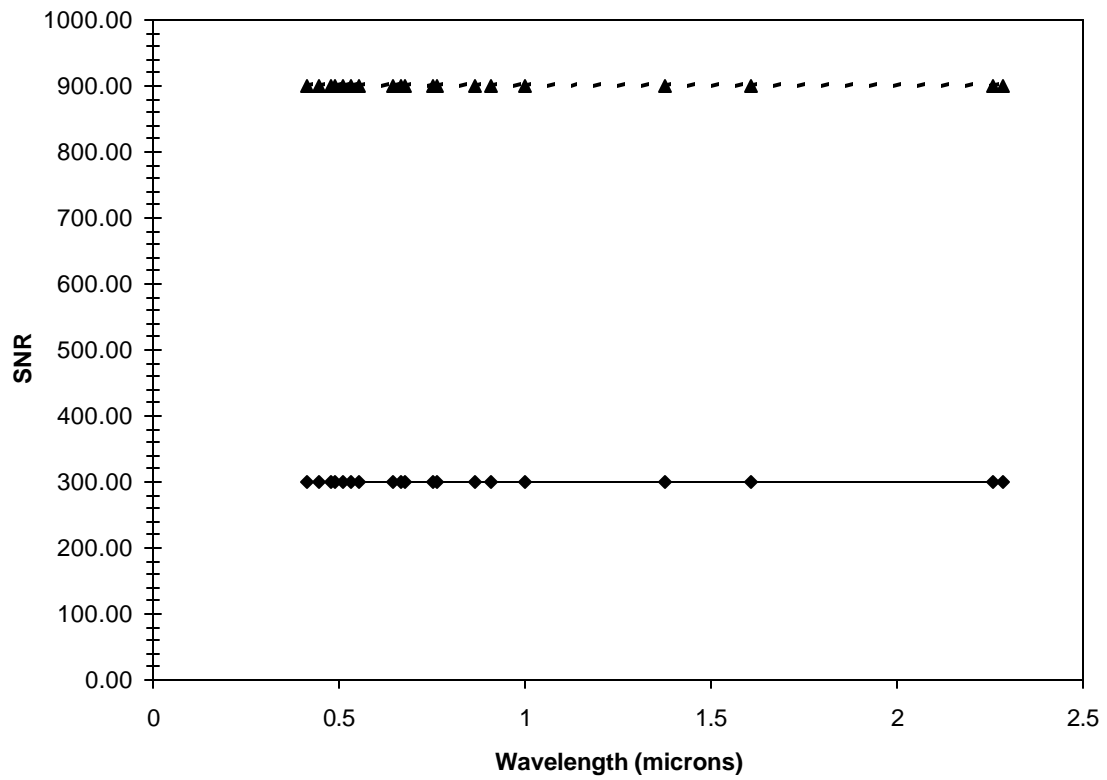


Figure 3.2.17 Plot of CW sensor Reflected Solar SNR requirement.

Table 3.2.30 CW sensor Reflected Solar SNR requirement.

Channel Center (μm)	Minimum SNR (THRESHOLD)	Minimum SNR (Goal)
0.412	300 (TBR)	900 (TBR)
0.443	300 (TBR)	900 (TBR)
0.477	300 (TBR)	900 (TBR)
0.490	300 (TBR)	900 (TBR)
0.510	300 (TBR)	900 (TBR)
0.530	300 (TBR)	900 (TBR)
0.550	300 (TBR)	900 (TBR)
0.570	300 (TBR)	900 (TBR)
0.645	300 (TBR)	900 (TBR)
0.667	300 (TBR)	900 (TBR)
0.678	300 (TBR)	900 (TBR)
0.750	300 (TBR)	900 (TBR)
0.763	300 (TBR)	900 (TBR)
0.865	300 (TBR)	900 (TBR)
0.905	300 (TBR)	900 (TBR)
1.0	300 (TBR)	900 (TBR)
1.38	300 (TBR)	900 (TBR)
1.61	300 (TBR)	900 (TBR)
2.26	300 (TBR)	900 (TBR)
2.285	300 (TBR)	900 (TBR)

As a THRESHOLD, the CW task sensor LWIR band (HES band 7) NEdN **shall** be less than or equal to the values in Table 3.2.31.

Table 3.2.31 CW sensor LWIR NEdN and NEdT @300K requirements.

Channel Center (cm^{-1})	Channel Center (μm)	NEdN ($\text{mW}/\text{m}^2 \text{ sr cm}^{-1}$)	NEdT @ 300 K (K)
893	11.2	0.17	0.1
813	12.3	0.18	0.1

3.2.7.2.1 Pixel Operability

A pixel is considered fully operable if the channels in the pixel meet all of the other channel requirements and following two conditions are satisfied:

1. The number of channels that fail the noise requirements plus the number of missing channels in planned band breaks is less than the percent failing in Table 3.2.32 for all spectral sub-regions and
2. The number of contiguous missing channels that fail the noise requirements not including planned band breaks is less than the cluster lengths in Table 3.2.32 for all spectral sub-regions.

A pixel is considered operable if the channels in the pixel meet all of the channel spatial, spectral, and temporal requirements and following two conditions are satisfied (note: a fully operable pixel is also operable):

- a. The number of channels that fail two times the noise requirements plus the number of missing channels in planned band breaks is less than the percent failing in Table 3.2.32 for all spectral sub-regions and
- b. The number of contiguous missing channels that fail two times the noise requirements not including planned band breaks is less than the cluster lengths in Table 3.2.32 for all spectral sub-regions.

A pixel is considered inoperable if it is not operable.

An outage is an inoperable pixel that is defined as a non-responsive (or operationally dead) pixel when the calibrated responsivity in every channel in a band is less than 1% of the mean spectral responsivity across the sub-region of the spectral band of the FPA of interest.

Discussion: Note the spectral responsivity is measured on a channel-by-channel basis.

As a THRESHOLD for the sounding tasks, there shall be no more than 5% (TBR) outages.

As a THRESHOLD, the sounder sensor(s) **shall** have at least 50% fully operable pixels.

As a THRESHOLD, the sounder sensor(s) **shall** have at least 84% operable pixels.

As a GOAL, the sounding sensor(s) spectral operability should be 100%.

The HES-DS shall have no more than 0.05% (TBR) neighboring inoperable pixels in a 62 LZA frame including diagonal neighbors on a rectangular grid.

The HES-SW/M **shall** have no more than 0.05% (TBR) neighboring inoperable pixels in a mesoscale frame including diagonal neighbors on a rectangular grid.

The VIS (Band 4) **shall** have at least 99.9% fully operable pixels.

The HES-CW Reflected < 1 um **shall** have at least 99.9% fully operable pixels for both the contiguous and the non-contiguous band implementations.

The HES-CW Reflected > 1 um **shall** have at least 87% operable pixels.

Figure 3.2.4 shows a graphical representation of each spectral region specified in the table.

Table 3.2.32 Spectral inoperability requirements.

Band	Sub-Region	Spectral Range (cm ⁻¹)	Cluster length for threshold channels	Total channel inoperability per sub-region
LWIR [Band-1]	1	650-665	< or = 5	45% (TBR)
	2	665-672	NONE	0% (TBR)
	3	672-722	< or = 5	10% (TBR)
	4	722-930	< or = 5	10% (TBR)
	5	930-960	< or = 5	25% (TBR)
	6	960-1080	< or = 5	10% (TBR)
	7	1080-1200	< or = 5	40% (TBR)
MWIR [Band-2] (option 1)	NA	1650-2150	< or = 5	25% (TBR)
MWIR [Band-2] (option 2)	NA	1210-1740	< or = 5	20% (TBR)
SWIR [Band-3]	1	2150-2230	< or = 5	20% (TBR)
	2	2230-2380	< or = 5	10% (TBR)
	3	2380-2390	NONE	0% (TBR)
	4	2390-2570	< or = 5	60% (TBR)
	5	2570-2720	< or = 5	15% (TBR)
<i>Total sounding operability</i>				20%
Reflected solar < 1 um [Band-5]	NA	0.4-1.0	0	0%
Reflected solar > 1 um [Band-6]	NA	1.0-2.285	0	0%
LWIR-CW [Band-7]	NA	11.2-12.3	0	0%

3.2.7.2.2 *Reserved*

3.2.7.2.3 *Reserved*

3.2.7.3 Radiometric Accuracy

3.2.7.3.1 *Absolute Accuracy*

The HES absolute radiometric accuracy is the unknown bias error in the measured radiance in each spectral channel, root-mean-squared with any random precision or repeatability component in a specific measurement period. It is specified in terms of a brightness temperature error at 300 K for emissive bands and percent of signal at 110% albedo for reflective bands.

As a THRESHOLD, the HES absolute accuracy **shall** be less than or equal to the values presented in Table 3.2.33. It should be less than or equal to the GOAL values.

Table 3.2.33 HES absolute accuracy THRESHOLD and GOAL requirements.

HES Band Number	Band/Task	Abs. Accuracy (%) THRESHOLD	Abs. Accuracy (%) GOAL	Abs. Accuracy (K) THRESHOLD	Abs. Accuracy (K) GOAL
1	LWIR – Sounding	NA	NA	1	0.5
2	MWIR – Sounding	NA	NA	1	0.5
3	SWIR – Sounding	NA	NA	1	0.5
4	VIS	5	3 (TBR)	NA	NA
5	Reflected Solar < 1 um - CW	3	TBD	NA	NA
6	Reflected Solar > 1 um - CW	3	TBD	NA	NA
7	LWIR - CW	NA	NA	1	0.5

3.2.7.3.2 *Relative Accuracy*

The relative radiometric accuracy is defined as the unknown bias error *between two arbitrary radiance measurements*, root-mean-squared with any random precision or repeatability component in a specific measurement period. The relative accuracy error is defined as the RMS variation in signal level, for all measurements in an ensemble (e.g. all

the pixels in a frame) illuminated by constant scene radiance. It is specified in terms of the NE_dN for emissive bands and percent of signal at 110% albedo for reflective bands.

All values presented are 1-sigma, and apply to the following categories:

- a) Swath to swath (where a swath is one traversal of the scan mirror, if present, in the east-west directions over the entire scene of interest).
- b) Scan position to scan position (where scan position refers to a location of the target within a swath). (TBR)
- c) Pixel to pixel.
- d) Band to band.
- e) Channel to channel.
- f) Calibration to calibration.

As a THRESHOLD, the HES relative accuracy difference **shall** be less than or equal to the values presented in Table 3.2.34. The HES relative accuracy difference should be less than or equal to the GOAL values.

Table 3.2.34 HES relative accuracy THRESHOLD and GOAL requirements.

HES Band Number	Band/Task	Rel. Accuracy (% Threshold Dynamic Range) THRESHOLD	Rel. Accuracy (%Threshold Dynamic Range) GOAL	Rel. Accuracy (in NE _d N) @ 250 K THRESHOLD	Rel. Accuracy (in NE _d N) @ 250 K GOAL
1	LWIR - Sounding	NA	NA	< or = NE _d N	< or = 1/3 NE _d N
2	MWIR - Sounding	NA	NA	< or = NE _d N	< or = 1/3 NE _d N
3	SWIR - Sounding	NA	NA	< or = NE _d N	< or = 1/3 NE _d N
4	VIS - Sounding	0.2 (TBR)	0.1 (TBR)	NA	NA
5	Reflected Solar < 1 um - CW	0.2	0.1	NA	NA
6	Reflected Solar > 1 um - CW	0.2	TBS	NA	NA
7	LWIR - CW	NA	NA	1	1/3

The relative radiometric accuracy **shall** be demonstrated by averaging a sufficiently large number of samples such that the residual temporal variation does not dominate the calculation.

3.2.7.3.3 Long-term Drift

The drift in absolute calibrated radiances for the CW task sensor reflective bands (HES bands 5 and 6) **shall** be less than 0.5% over the instrument lifetime.

All calibration sources used **shall** be traceable to National Institute of Standards and Technology (NIST) standards.

3.2.7.3.4 Ground Calibration

The HES reflective bands (HES bands 4-6) **shall** be calibrated on the ground, pre-launch. The HES reflective bands (HES bands 4-6) calibration **shall** be a full-system and full-aperture spectral response characterization, i.e. the clear aperture of every component in the optical train is subject to calibration.

3.2.7.3.5 On-Orbit Calibration

The HES **shall** have on-board spectral response calibration for the emissive bands (HES bands 1-3, and 7), i.e. the clear aperture of every component in the optical train is subject to calibration.

All emissive band calibrations **shall** be performed often enough to meet all accuracy requirements.

Calibration of the CW task sensor Reflected Solar bands (HES bands 5 and 6) **shall** be performed on-board during the life of the instrument to meet all accuracy requirements. An on-board, full optical train, full aperture calibrator **shall** be used to perform calibrations during the life of the instrument performing this task.

3.2.7.3.6 On-Orbit Electronic Calibration

A system for determining the linearity of the electronics and analog to digital converters **shall** be incorporated.

The calibration signal input non-linearity **shall** be less than 0.1% (TBR) of full scene, and the amplitude **shall** be greater than the dynamic range of the channel.

The calibration signal **shall** be inserted as close to the detector output signal as practical in the electronics chain.

3.2.7.3.7 Polarization Sensitivity

Polarization sensitivity is defined as the ratio of the difference between maximum and minimum output to the sum of the maximum and minimum output obtained when the plane of incoming 100% linearly polarized radiation is rotated through 180 degrees.

All HES bands with wavelengths <3 um (other than HES band 4) **shall** have less than 3% (TBR) polarization sensitivity and they should have less than 1% (TBR) polarization sensitivity.

The difference in polarization sensitivity between channels **shall** be less than 2% (TBR), and should be less than 1% (TBR).

The uncertainty in the polarization sensitivity within a channel **shall** be less than 1% (TBR) and should be less than 0.5% (TBR).

The polarization sensitivity requirements **shall** be met at all Earth-viewing angles throughout the life of the mission and the sensitivity requirements should be met over the entire field-of-regard.

3.2.7.3.8 Temperature Monitoring

Optical and structural elements that influence the radiometric response of emissive bands (HES bands 1-3, and 7) **shall** be temperature monitored and telemetered for calibration ground processing.

Calibration corrections using the temperature data **shall** have an error ≤ 0.1 K precision (TBR) between calibrations.

3.2.7.4 System Linearity

The corrected system radiometric response non-linearity for each detector element **shall** be less than 1% RMS (TBR) over the full dynamic range to be stable enough to meet all radiometric performance requirements.

3.2.7.5 Reserved

3.2.7.6 Stray Light

3.2.7.6.1 Bright scene saturation

Any HES reflective band pixel (HES bands 4-6) located more than 5 (TBR) pixels away from any pixel containing a bright cloud edge of a 100% albedo source **shall** meet all performance requirements.

Discussion: Although the bright pixel edge may be small in spatial extent compared to the pixel size, the physical extent of a bright cloud edge of 100% albedo may also be many times larger than the pixel.

Any HES reflective band pixel (HES bands 4-6) located more than 3 (TBR) and less than 5 (TBR) pixels away from any pixel containing a bright cloud edge of a 100% albedo source should have a signal to noise ratio no less than half (TBR) that allowed in section 3.2.7.2.

3.2.7.6.2 *Sun Glint*

A Sun glint is defined as a signal of 200x (TBR) the 100% albedo level.

Any HES reflective band pixel (HES bands 4-6) located more than 5 (TBR) pixels away from any pixel containing a Sun glint **shall** meet all performance requirements.

Any HES reflective band pixel (HES bands 4-6) located more than 3 (TBR) and less than 5 (TBR) pixels away from any pixel containing a Sun glint should have a signal to noise ratio no less than half (TBR) that allowed in section 3.2.7.2.

3.2.7.6.3 *Reserved*

3.2.8 Image Navigation and Registration

3.2.8.1 INR Scope

Image navigation refers to the determination of the location of each image pixel relative to a fixed reference coordinate system. Image registration refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Mission-level Image Navigation and Registration (INR) requirements apply to pixels and encompass the combined system performance of the HES, spacecraft and ground processing system.

3.2.8.2 INR Functions

This section defines several INR-related functions to be included in the HES and associated ground system.

3.2.8.2.1 *Star Sensing*

If star sensing is required to meet navigation requirements, the HES **shall** have an on-board star catalog provided by the HES vendor, which is loadable and modifiable from the ground, containing an identification (ID) number, right ascension, declination, proper motion, and instrument magnitude for each star.

If star sensing is required to meet navigation requirements, the HES **shall** autonomously acquire stars at a rate and accuracy required to meet INR requirements.

In addition to autonomous star sensing, the HES **shall**, when commanded, acquire stars from a HES-GS list of target stars that will be within the nominal field of regard for the next 26 hours. The target star list will consist of star ID and viewing time windows in Coordinated Universal Time (UTC) for each star.

3.2.8.2.2 *Pointing Compensation Profiles*

The HES-GS may uplink pointing compensation data for certain predictable pointing errors, such as diurnal orbit errors, thermal distortion, and sensor misalignment. The maximum range of predictive compensation will be ± 1.0 degrees North/South and East/West.

The HES **shall** include the capability to compensate its scanning profile using the uplinked correction data. Characteristics of the correction profiles are TBD.

3.2.8.3 INR Performance Requirements

All INR requirements listed herein apply to the end-to-end system, taking all instrument, spacecraft, and ground processing effects into account. INR errors for any given pixel(s) can be determined through analysis and simulation, while on-orbit verification will require using landmarks in an image.

Unless otherwise specified, all INR requirements in this document are specified as North/South and East/West angles, in microradians, 3-sigma, and refer to all hours of operation. In addition, 3-sigma is interpreted as the arithmetic mean, plus or minus three times the square root of the variance for a population of 100 consecutive observations.

In this section, "image" or "frame" are synonymous, and refer any programmed scan area data set ranging from a full disk down through the mesoscale in pixel space, as opposed to detector sample space.

The ground sample distance (GSD) listed here is defined in section 3.2.5.2. The ground sample angle (GSA) is associated angular distance.

3.2.8.3.1 Navigation

Navigation error is the angular location knowledge error of pixels or features in an image.

The navigation error for each HES task **shall** not exceed the THRESHOLD values in Table 3.2.35 for pixels on the Earth's disk, except during eclipse periods.

The navigation error should not exceed the GOAL values in Table 3.2.35, except during eclipse.

For up to a four-hour period that includes an eclipse of the Sun, the HES navigation error **shall** not exceed the "eclipse THRESHOLD" values in Table 3.2.35. The phasing of the four-hour relaxation relative to the eclipse may be design-specific and will be recommended by the HES contractor.

The navigation error should not degrade for the entire day.

Table 3.2.35 - HES Navigation Requirements.

HES Task	THRESHOLD	Eclipse THRESHOLD	Goal
DS	0.375 IR GSA	0.5675 IR GSA	0.1875 IR GSA
SW/M	0.375 IR GSA	0.5675 IR GSA	0.1875 IR GSA
CW	Max. of 0.75 (TBR) GSA or 6.75 urad	NA	Max. of 0.375 (TBR) GSA or 5.25 urad (TBR)

3.2.8.3.2 Frame to Frame Registration

Frame to frame registration error is the difference in navigation error for any given pixel in two consecutive images. Since images may be 60 minutes apart, these requirements apply over 60 minute periods.

Frame to frame registration errors **shall** not exceed the THRESHOLD values in Table 3.2.36.

Frame to frame registration error should not exceed the GOAL values in Table 3.2.36.

Table 3.2.36 - HES Frame-to-Frame Registration Requirements

HES Task	THRESHOLD	Goal
DS	0.375 IR GSA	0.1875 IR GSA
SW/M	0.375 IR GSA	0.1875 IR GSA
CW	Max. of 0.75 (TBR) GSA or 6.75 urad	Max. of 0.375 (TBR) GSA or 5.25 urad (TBR)

3.2.8.3.3 Within Frame, Non-Adjacent Pixel Registration

Within-frame, non-adjacent registration error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image.

Within-frame, non-adjacent registration error **shall** not exceed the THRESHOLD values in Table 3.2.37.

Within-frame, non-adjacent registration error should not exceed the GOAL values in Table 3.2.37.

Table 3.2.37 - HES Within-Frame, Non-Adjacent Pixel Registration Requirements.

HES Task	THRESHOLD	Goal
DS	0.375 IR GSA	0.1875 IR GSA
SW/M	0.375 IR GSA	0.1875 IR GSA
CW	Max. of 0.75 (TBR) GSA or 6.75 urad	Max. of 0.75 (TBR) GSA or 5.25 urad (TBR)

3.2.8.3.4 Within Frame, Adjacent Pixel Registration

Within-frame, adjacent registration error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line-to-line and single integration image to single integration image.

Within-frame, adjacent registration error **shall** not exceed the THRESHOLD values in Table 3.2.38.

Within-frame, adjacent registration error should not exceed the GOAL values in Table 3.2.38.

Table 3.2.38 HES Within-Frame and Adjacent Registration Requirements.

HES Task	THRESHOLD	Goal
DS	0.375 IR GSA	0.1875 IR GSA
SW/M	0.375 IR GSA	0.1875 IR GSA
CW	Max. of 0.75 (TBR) GSA or 6.75 urad	Max. of 0.75 (TBR) GSA or 5.25 urad (TBR)

3.3 Design Requirements

3.3.1 On-Board Processors (OBP)

3.3.1.1 Commandability of Redundant On-Board Processor Configuration

The operational configuration of OBP redundant components **shall** be commandable and configurable from the ground.

Discussion: On-Board Processors refers to the CPU, RAM, ROM, NV-RAM, clocks, component interface and monitor circuitry such as temperature, voltage, and current sensors.

3.3.1.2 Flight Load Non-volatile Memory

The entire flight software image **shall** be contained in non-volatile memory at launch.

3.3.1.3 Ground Commandable OBP Reboot/Reinitialization

The OBP **shall** provide for reset by ground command of software for recovery from instrument anomalies, including software anomalies.

3.3.1.4 Deterministic Power-on Configuration

The OBP **shall** initialize upon power-up into a predetermined configuration.

3.3.1.5 Failsafe Recovery Mode

The instrument **shall** provide a failsafe recovery mode dependant on a minimal hardware configuration that is capable of accepting and processing a minimal command subset sufficient to load and dump memory.

In failsafe recovery mode the instrument **shall** be commandable to begin execution at a specified memory address.

3.3.2 Flight Software

3.3.2.1 Language and Methodology

All software developed for the HES instrument **shall** be developed with ANSI/ISO standard languages and a widely-accepted, industry-standard, formal software design methodology. Minimal use of processor-specific assembly language is permitted for

certain low-level programs such as interrupt service routines and device drivers with NASA approval.

3.3.2.2 Software Module Upload

The flight software **shall** be programmable on-orbit to allow for new versions of software segments and table values to be loaded from the ground without computer restart.

The flight software **shall** be capable of being uploaded in modules, units, segments, and objects, which **shall** be usable immediately after completion of an upload of the modified modules, units, segments, and objects.

Activation of the modified modules, units, segments, and objects **shall** not require completion of an upload of the entire flight software image.

Discussion: Software ideally will be patchable without having to replace the entire image.

3.3.2.3 Flexibility and Ease of Software Modification

The HES flight software design **shall** be flexible and table-driven for ease of operation and modification.

The HES flight software **shall** be rigid in terms of scheduling and prioritization of critical processing tasks to ensure timely completion.

All software data that are modifiable and examinable by ground operators **shall** be organized into tables that can be referenced by table number so table data can be loaded and dumped by the ground without reference to memory address.

Discussion: Ground software and databases ideally will not need to change when data are relocated by a recompilation of the flight software.

The definition of instrument commands within the ground database **shall** not be dependent on physical memory addresses within the flight software.

Discussion: All commands processed by the flight software (with the exception of loads and dumps by address) ideally will be interpreted by the flight software without the use of any uploaded physical address. Existing command definitions in the database ideally will be unaffected when the flight software is recompiled.

3.3.2.4 Version Identifiers in Embedded Code

All software and firmware versions **shall** be implemented with an internal identifier (embedded in the executive program) that can be included in the instrument engineering data.

This software identifier **shall** be keyed to the configuration management process so that the exact version of software and firmware residing in the instrument can be determined at any time.

3.3.2.5 Flight Processor Resource Sizing

During development, flight processors providing computing resources for instrument subsystems **shall** be sized for worst-case utilization not to exceed the capacity shown below (measured as a percentage of total available resource capacity):

Flight Processor Resource Utilization Limits			
	S/W PDR	S/W CDR	S/W AR
RAM Memory	40%	50%	60%
ROM Memory	50%	60%	70%
CPU	40%	50%	60%

3.3.2.6 Software Event Logging

The flight software **shall** include time-tagged event logging in telemetry.

The event messages **shall** capture all anomalous events, redundancy management switching of instrument components, and important system performance events.

All flight software **shall** utilize a common format for event messages.

The flight software **shall** provide a means for ground command to enable and disable queuing of individual event messages.

The flight software **shall** buffer a minimum of 1000 event messages while the event messages are queued for telemetering to the ground.

The event message queue **shall** be configurable by ground command to either a) discard the new events, or b) overwrite oldest events when the queue is full.

The flight software **shall** maintain counters for:

- a) The total number of event messages generated.
- b) The number of event messages discarded because of queue overflow.
- c) The number of event messages not queued due to being disabled.

3.3.2.7 Warm Restart

The flight software **shall** provide a restart by ground command with preservation of the event message queue and memory tables.

3.3.2.8 Memory Tests

The flight software **shall** provide a mechanism to verify the contents of all memory areas.

3.3.2.9 Memory Location Dump Capability

The flight software, and associated on-board computer hardware, **shall** provide the capability to dump any location of on-board memory to the ground upon command.

The flight software memory dump capability **shall** not disturb normal operations and instrument data processing.

3.3.2.10 Telemetry

Telemetry points sampled by the instrument **shall** be controlled by an on-orbit modifiable table.

The sample rate of every instrument telemetry point **shall** be controlled by an on-orbit modifiable table.

3.3.3 Mechanical

Each instrument unit structure **shall** possess sufficient strength, rigidity and other characteristics required to survive the critical loading conditions that exist within the envelope of handling and mission requirements.

3.3.3.1 Design and Test Factors of Safety

The instrument contractor **shall** use the prototype factors of safety specified in NASA-STD-5001 for analysis and verification of structural units not containing beryllium.

The instrument contractor **shall** use a proof test factor, yield and ultimate factors of safety of 1.4, 1.45 and 1.6, respectively, for structural elements containing beryllium.

3.3.3.2 Design Limit Loads

The structure **shall** be capable of withstanding all limit loads without loss of any required function.

Discussion: Limit loads are defined as all worst case load conditions including temperature effects from the environments expected during all phases of the structure's service life including manufacturing, ground handling, transportation, environmental testing, integration, pre-launch, launch, and on-orbit operations and storage.

3.3.3.3 Non-Linear Loads

The flight unit structures **shall** be capable of withstanding redistribution of internal and external loads resulting from any non-linear effects including deflections under load.

3.3.3.4 Yield Strength

The flight unit structures **shall** be able to support yield loads without detrimental permanent deformation.

Discussion: Strength requirements are specified in terms of yield and ultimate loads. Yield loads are limit loads multiplied by prescribed factors of safety.

While subjected to any operational load up to yield operational loads, the resulting deformation **shall** not interfere with the operation of the instrument flight unit.

3.3.3.5 Ultimate Strength

The unit structures **shall** be able to support ultimate loads without failure for at least 3 seconds including ultimate deflections and ultimate deformations of the flight unit structures and their boundaries. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply.

Discussion: Strength requirements are specified in terms of yield and ultimate loads. Ultimate loads are limit loads multiplied by prescribed factors of safety.

3.3.3.6 Structural Stiffness

Stiffness of the flight unit structures and their attachments **shall** be designed by consideration of their performance requirements and their handling, transportation and launch environments.

Special stowage provisions **shall** be used if required to prevent excessive dynamic amplification during handling, transportation and transient flight events.

3.3.3.7 Unit Stiffness

The fundamental resonant frequency of an instrument flight unit **shall** be 50 Hz (TBR) or greater when the flight unit is constrained at its spacecraft interface.

3.3.3.8 Material Properties

Material properties **shall** be based on sufficient tests of the material meeting approved specifications to establish design values on a statistical basis.

Design values **shall** account for the probability of structural failures and loss of any required function due to material variability.

The instrument contractor **shall** specify the source and statistical basis of all material properties used in the design.

The effects of temperature on design values **shall** be considered.

3.3.3.9 Critical Members Design Values

For critical members, design values **shall** be selected to assure strength with a minimum of 99 percent probability and 95 percent confidence.

Structural members are classified as critical when their failure would result in loss of structural integrity of the flight units.

3.3.3.10 Redundant Members Design Values

For redundant members, design values **shall** be selected to assure strength with a minimum of 90 percent probability and 95 percent confidence.

Structural members are classified as redundant when their failure would result in the redistribution of applied loads to other structural members without loss of structural integrity.

3.3.3.11 Selective Design Values

As an exception to Sections “Critical Members Design Values” and “Redundant Members Design Values,” greater design values may be used if a representative portion of the material used in the structural member is tested before use to determine that the actual strength properties of that particular structural member will equal or exceed those used in the design.

3.3.3.12 Structural Reliability

The strength, detailed design, and fabrication of the structure **shall** prevent any critical failure due to fatigue, corrosion, manufacturing defects and fracture throughout the life of the instrument resulting in the loss of any mission objective.

Accounting for the presence of stress concentrations and the growth of undetectable flaws, the instrument flight unit structures **shall** withstand loads equivalent to four complete service lifetimes.

While subjected to any flight operational load up to limit flight operational loads, the resulting deformation of the residual instrument flight unit structures **shall** not interfere with the operation of the instrument flight unit.

After an load up to limit loads, the resulting permanent deformation of the residual instrument flight unit structures **shall** not interfere with the operation of the instrument flight unit.

3.3.3.13 Mechanisms

Deployment, sensor, pointing, drive, separation mechanisms, and other moving mechanical assemblies may be designed using MIL-A-83577B and NASA TP-1999-206988.

All instrument mechanisms **shall** meet performance requirements while operating in an Earth gravity environment with any orientation of the gravity vector (TBR).

Moving mechanical assemblies **shall** have torque and force ratios per section 2.4.5.3 of GEV-SE using a NASA approved classification of each spacecraft mechanism.

For all operating points of the actuators, all rotational actuators **shall** have available a continuous maximum torque output greater than 7.0 milli-Newton meters.

For all operating points of the actuators, all linear actuators **shall** have available a continuous maximum force output greater than 0.28 N.

For mechanisms using closed-loop control, gain and phase margins **shall** be greater than 12 dB, and greater than 40 degrees, respectively. The margins **shall** include the effects of the dynamic properties of any flexible structure.

All instrument mechanisms requiring restraint during launch **shall** be caged during launch without requiring power to maintain the caged condition.

All instrument mechanisms requiring restraint **shall** be released from a caged condition by command.

All instrument mechanisms requiring restraint **shall** be returned to a caged condition ready for launch by either command or by manual actuation of an accessible caging device.

3.3.3.14 Magnetic

The instrument **shall** not have uncompensated magnetic moments greater than 0.0005 ampere-turn meter-square per kilogram of mass (TBR).

3.3.3.15 Pressurized Units

Instruments with pressurized systems **shall** follow the requirements in accordance with the EWR-127-1 and MIL-STD-1522A for the design of pressurized systems.

The instrument **shall** have no open fluid reservoirs when delivered to the spacecraft contractor.

3.3.4 Thermal – Design and Construction Standards

3.3.4.1 Temperature Limits

The instrument contractor **shall** establish Mission Allowable Temperatures (MAT) for the instrument with at least 5 degrees C of analytical/test uncertainty.

Discussion: Thermal margin is defined as the temperature delta between MAT versus the bounding predictions plus analytical uncertainty.

Figure 3.3.1 Temperature Requirement Graphic

TBS

The instrument **shall** maintain thermally independent units and their internal components within Mission Allowable Temperatures (MAT) limits during all flight operational conditions including bounding worst-case environments.

3.3.4.2 Out-gassing Temperature Requirements

The instrument **shall** maintain the thermally independent units and their internal components with Out-gassing Allowable Temperatures (OAT) during all out-gassing procedures.

3.3.4.3 Non-Operational Temperature Requirements (NOT)

The Non-Operational Temperatures (NOT) range **shall** extend at least 20 degrees C warmer than the hot MAT and at least 20 degrees C colder than the cold MAT.

The cold Non-Operational Temperature **shall** be –25 degrees C or colder.

3.3.4.4 Thermal Control Hardware

There **shall** be two or more serial and independent controls for disabling any heater where any failed on condition would cause over-temperature conditions or exceed the instrument power budget.

Discussion: Independent controls include thermostats, relays, and other switches.

The instrument heaters **shall** be sized to have 25% margin for worst-case conditions.

When the instrument is off, instrument survival heaters **shall** maintain independent unit temperatures above non-operational limits.

Discussion: The only intended use of survival heaters will be to maintain non-operational temperatures when the instrument is off.

Instrument survival heaters **shall** be thermostatically controlled.

3.3.5 Multi-Layer Insulation

Multi-Layer Insulation (MLI) **shall** have provisions for venting and electrical grounding to prevent Electro-Static Discharge (ESD).

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APPENDICIES

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A OPEN OCEAN GOAL REQUIREMENTS

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A.1 HES Goal Requirements Description and Overview

The GOAL task will be performed by the HES, located on a satellite in geostationary orbit. The GOAL task is open ocean (OO) imaging being performed at high (4 km or finer) spatial resolution.

Critical performance parameters for the OO task of the HES are the spectral coverage. This improved spectral coverage for the OO task will meet the needs of NOAA in ocean areas that have not been well covered spatially or spectrally by the current imager or sounder, due to lack of spectral coverage in the reflected solar spectrum.

The **shall** and should requirements in this section of the PORD will only be effective to the extent that this GOAL task is studied.

A.1.1 GOAL TASK SENSOR REQUIREMENTS

A.1.1.1 Scope

It is anticipated that the OO task will be met by one of three general classes of instruments: a multiple band radiometer, where the number of bands is nominally less than 10, a multiple band radiometer, where the number of bands is nominally greater than 10, or a spectrometer yielding higher spectral resolution at all wavelengths in the range producing more than 100 channels. Combinations of these instruments are not excluded.

A.1.1.2 Spectral Requirements

A.1.1.2.1 Number of Spectral Bands

The number of spectral bands describes how many spectral regions are covered in the sensor(s). The OO task requires the detection of scene radiance over the one Reflected Solar band < 1 um to meet the THRESHOLD.

A.1.1.2.2 Spectral Range

To meet the OO task, the instrument **shall** meet the spectral range and band continuity requirements listed in Table A 1

Table A 1 OO Sensor THRESHOLD and GOAL Bands

Task and Priority	Band	Spectral Range (um)	Band Continuity
OO THRESHOLD	Reflected Solar < 1 um	0.4-1.0	Non-contiguous
OO GOAL	Reflected Solar < 1 um	0.4-1.0	Contiguous

A.1.1.2.3 OO Spectral Channels, Resolution, and Resolving Power

The THRESHOLD OO channel centers within the Reflected Solar < 1 um band **shall** match the values in Table A.2.

The GOAL OO channel centers within the Reflected Solar < 1 um band should also match the values in Table A 2.

Table A 2 OO THRESHOLD & GOAL Channels Centers and Resolution

Nominal Threshold Channel Center Wavelength (um)	Nominal Threshold Resolution (um)	Threshold tolerance on center wavelength (um)	Lower 50% Response Point Threshold	Upper 50% Response Point Threshold
0.412 (GOAL)	0.02	+/- 0.002 (TBR)	0.402 +/- 0.0015	0.422 +/- 0.0015
0.443 (THRESHOLD)	0.02	+/- 0.0011 (TBR)	0.433 +/- 0.0015	0.453 +/- 0.0015
0.477 (GOAL)	0.02	+/- 0.002 (TBR)	0.467 +/- 0.0015	0.487 +/- 0.0015
0.490 (THRESHOLD)	0.02	+/- 0.0012 (TBR)	0.480 +/- 0.0015	0.500 +/- 0.0015
0.510 (GOAL)	0.02	+/- 0.0015 (TBR)	0.500 +/- 0.0015	0.520 +/- 0.0015
0.530 (THRESHOLD)	0.02	+/- 0.0012 (TBR)	0.520 +/- 0.0015	0.540 +/- 0.0015
0.550 (THRESHOLD)	0.02	+/- 0.005 (TBR)	0.540 +/- 0.0015	0.560 +/- 0.0015
0.645 (THRESHOLD)	0.02	+/- 0.004 (TBR)	0.635 +/- 0.0015	0.655 +/- 0.0015
0.667 (THRESHOLD)	0.01	+0.001,-0.002 (TBR)	0.662 +/- 0.0015	0.672 +/- 0.0015
0.678 (GOAL)	0.01	+/- 0.001(TBR)	0.673+/- 0.0015	0.683 +/- 0.0015
0.750 (GOAL)	0.02	+/- 0.002 (TBR)	0.740 +/- 0.0015	0.760 +/- 0.0015
0.763 (GOAL)	0.02	+/- 0.0015 (TBR)	0.753 +/- 0.0015	0.773 +/- 0.0015
0.865 (THRESHOLD)	0.02	+/- 0.0022 (TBR)	0.855 +/- 0.0015	0.875 +/- 0.0015
0.905 (GOAL)	0.035	+/- 0.0023 (TBR)	0.887 +/- 0.0015	0.922 +/- 0.0015

As a GOAL, the OO task sensor(s) spectral resolution should be 0.01 μm for the OO task threshold channels.

As a GOAL, the OO task sensor(s) spectral resolution and number of channels should conform to the values presented in Table A3.

Table A 3 OO sensor GOAL spectral resolution

Band	Nominal GOAL Channel Center Wavelength (μm)	Nominal GOAL Resolution (μm)	Threshold tolerance on center wavelength (μm)	Lower 50% Response Point Threshold	Upper 50% Response Point Threshold
Reflected Solar < 1 μm	0.407 through 0.987	0.01	+/- 0.001 (TBR), centered on 0.667 +/- 0.001	+/- 0.0015, e.g. 0.662 +/- 0.0015	+/- 0.0015, e.g. 0.672 +/- 0.0015

A.1.1.2.3.1 On-Board Spectral Compression

The THRESHOLD channel set will be downlinked upon ground command, excluding missing channels due to planned band breaks (see section A.1.1.2.7).

A.1.1.2.4 Spectral Response

A.1.1.2.4.1 Out-of-Channel Response

For the OO task, the out-of-channel response is defined in the equation as one minus the integrated response between the 1% response points divided by the integrated response from 0.3 microns to 20 microns. The 1% response point is defined as 1% of the peak spectral response of the system.

For the HES-OO task, the 1% response points **shall** each lie within 1.5 (TBR) times the spectral resolution element width from 50% response point.

The integrated response in the region between the 50% point and the 1% point shall be less than TBD percent of the integrated response from 0.3 microns to 20 microns.

Out-of-channel response shall be less than 1% of the total signal when viewing a 110% albedo scene above the atmosphere assuming no attenuation.

$$1 - \left(\frac{\int_{-I_{1\%}}^{+I_{1\%}} N(I)R(I)dI}{\int_{I_{0.3 \mu m}}^{I_{20 \mu m}} N(I)R(I)dI} \right) \leq 0.01 \quad \text{where}$$

$N(I)$ = 300 K blackbody or 100% albedo and
 $R(I)$ is the channel relative spectral response

Out-of-Channel Response Equation

A.1.1.2.5 Spectral Purity

Not applicable for OO task.

A.1.1.2.6 Spectral Knowledge and Stability

Not applicable for OO task.

A.1.1.2.7 Spectral Band Breaks

All spectral band breaks must be submitted to the government for approval.

A.1.1.3 Scan Requirements

A.1.1.3.1 Ground Sample Rate

The GSR THRESHOLD requirements for the OO task **shall** be greater than or equal to the values presented in Table A.4.

GSR GOAL values should be greater than or equal to the values presented in Table A.4.

Table A 4 OO THRESHOLD and GOAL GSR

TASK	GSR THRESHOLD (Hz)	GSR GOAL (Hz)
OO	393	6290 / GSD ²

A.1.1.3.2 Scan Direction

The dominant direction of instrument "scan" **shall** be in the East-West directions for the OO task. To accommodate a possible seasonal yaw flip, "scanning" and stepping shall be possible in North to South, South to North, West to East, and East to West directions.

Ground sample data acquisition should begin with the northernmost coordinate and proceed south.

A.1.1.3.3 Scan Flexibility

The OO task sensor THRESHOLD requirements **shall** be capable of providing arbitrary scan areas of open ocean anywhere when commanded. For the OO task, this area is no smaller than 400 km x 400 km and ranges through at least the OO coverage region, with areas in integer multiples of the effective pixel array size.

Discussion: The effective pixel array size includes inefficiencies due to image rotation and is defined after calibration and navigation. It is unique to each design.

The scan area and geographic location GOAL should be selectable from one frame to the next.

A.1.1.3.4 Scan Efficiency

A.1.1.3.4.1 Within Frame Scan Efficiency

Discussion: There are no requirements on within frame scan efficiency. However, it is expected that the scan efficiency values for the OO sensor will be similar to the current class of instruments operating in the Reflected Solar (~3 um or less) at 95%.

A.1.1.3.4.2 Overall Task Efficiency

As a THRESHOLD, the OO sensor **shall** be capable of continuously performing OO tasks, i.e. provide the required coverage within the specified time, meeting all requirements.

A.1.1.4 Coverage Area Requirements

The HES sensor performing the OO task **shall** scan the OO task area such that the centroid to centroid distance between neighboring pixels does not exceed the required Ground Sample Angle not including diagonal neighbors of a rectangular grid (TBR) and not including pixels outages within limitations defined in section A.1.1.5.5.

The dimensional bounds for the THRESHOLD performance of the OO task is the ocean inside the 62 degree LZA of $\sim 6.8 \times 10^7 \text{ km}^2$. The area is shown graphically for the east and west satellites in Figure A 1.

Discussion: Each task has a primary geographical scan region, but is required to perform scans of other regions for operational flexibility or back-up functionality.

As a THRESHOLD, the HES sensor(s) **shall** acquire an OO frame(s) when commanded.

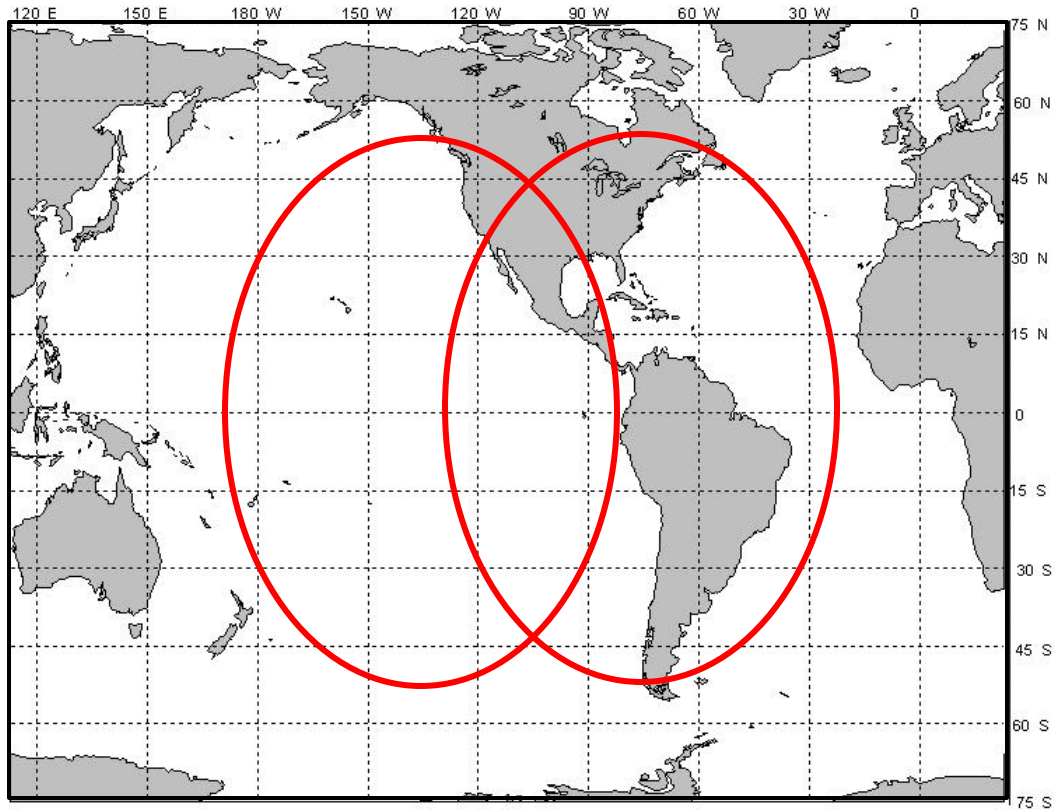


Figure A 1 Approximate 62-degree LZA coverage regions as seen from east and west satellite positions. Note the land area has not been removed in this figure.

A.1.1.5 Spatial Sampling Requirements

A.1.1.5.1 Field of Regard

The field of regard (FOR) is defined as an angular diameter through which the instrument can detect any instrument-external source of interest. The diameter is centered at the SSP and the angle is measured at the instrument. This field of regard is unvignetted.

Discussion: For HES, these sources include at least space, which is used for instrument background subtraction when appropriate, and emission from the Earth's atmosphere and surface.

The unvignetted (FOR) **shall** be large enough to accommodate the calibration and navigation needs of the HES OO task being addressed by the instrument.

A.1.1.5.2 Ground Sample Distance and Angle

The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, *as measured at the satellite sub point*, defines the ground sample distance (GSD). A two-dimensional pixel is defined by the GSD in the east/west and north/south dimensions, therefore a single GSD quantity is specified for each task and each band required for the task.

Discussion: The associated ground sample angle (GSA) is constant for all scan position and satellite altitude geometry. Often, in the document, the GSD is referenced with the caveat that the actual GSD is calculated from the GSA.

The OO sensor **shall** produce pixels no larger than the THRESHOLD GSD and GSA values presented in Table A 5. It should also produce pixels as small as the GOAL values presented in Table A 5.

Table A 5 OO task sensor THRESHOLD and GOAL GSD and GSA capabilities

Band	THRESHOLD		GOAL	
	GSD (km)	GSA (microradians)	GSD (km)	GSA (microradians)
OO	4	112	1	28

A.1.1.5.3 Pixel Spatial Binning

Any design achieving less than the THRESHOLD GSD, for any task, **shall** perform on-board spatial pixel binning when commanded, such that the effective GSD is equal to the THRESHOLD value $\pm 25\%$ and all other THRESHOLD requirements are satisfied. (TBR)

A.1.1.5.3.1 Detector Sample Ground Footprint

Discussion: The OO reflective bands are subject to MTF requirements (section A.1.1.5.3.3).

A.1.1.5.3.2 Geometric Shape

Discussion: There is no requirement on the geometric shape of the footprint as long as all other THRESHOLD spatial sampling requirements are satisfied. (TBR)

A.1.1.5.3.3 Modulation Transfer Function

The spatial resolution of the OO reflective bands is defined by the system modulation transfer function (MTF). The sensor(s) **shall** meet the THRESHOLD requirements in Table A 6 in both east/west and north/south directions after any ground processing including spacecraft jitter as detailed in the HES UIID and GIRD. The sensor(s) should meet the THRESHOLD requirements in Table A 6 in both east/west and north/south directions after any ground processing including spacecraft jitter as detailed in the HES UIID and GIRD.

Table A 6 OO task Reflected Solar band MTF requirement for THRESHOLD spatial resolution

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
32.0	1125	0.90 (TBR)
16.0	2250	0.73 (TBR)
10.66	3375	0.53 (TBR)
8.0	4500	0.32 (TBR)

Table A 7 OO task Reflected Solar band MTF requirement for GOAL spatial resolution

Spatial Frequency		System MTF
(km/cyc)	(cyc/rad)	
8.0	4500	0.90 (TBR)
4.0	9000	0.73 (TBR)
2.67	13500	0.53 (TBR)
2.0	18000	0.32 (TBR)

A.1.1.5.4 Co registration

Channel-to-channel registration error, or co-registration, is the difference in pointing between spectral channels for any given pixel in the same frame, where the pointing is defined by the centroid location of each channel within a band.

Discussion: Since OO imaging involves the combination of data from each of the individual spectral bands, it is vital that the energy detected in each spectral channel from these task sensor(s) emanate from the same geographic area as

closely as possible. This becomes especially important in regions of strong gradients. The requirements specify how well the HES channels must be registered to each other.

As a THRESHOLD, the centroid co-registration errors in the OO task sensor with the threshold GSD **shall** not exceed 0.25 GSA or 28 urad. Values are written as an absolute angle.

As a GOAL, the centroid co-registration errors in the OO task sensor with the threshold GSD should not exceed 0.1 GSA or 11 urad. Values are written as an absolute angle.

At the GOAL GSD of 1km, the co-registration should have equivalent performance as a fraction of the GSA, as those used for the threshold GSD.

A.1.1.5.5 Pixel Operability

An OO task pixel is considered fully *operable* if the channels in the pixel meet all other channel requirements and the following two conditions are satisfied:

1. the number of channels that fail the noise requirements plus the number of missing channels in planned band breaks, if any, is less than the percent failing in Table A.8.
2. the number of contiguous missing channels that fail the noise requirements not including planned band breaks is less than the cluster lengths of 1.

A pixel is considered non-responsive, or an outage, when it is inoperable *and* the calibrated responsivity in each spectral channel is less than 10% (TBR) of the mean responsivity for the same channel across the entire focal plane array.

Discussion: The requirements below are specified per HES GOAL band.

As a THRESHOLD, the OO task **shall** have greater than or equal to the percentage of fully operable pixels presented in the Table A.8. As a THRESHOLD, the OO task **shall** have fewer outages than the values presented in Table A.8.

Table A 8 OO THRESHOLD pixel operability and outage requirements

Band	Operability THRESHOLD	Outages THRESHOLD
Reflected Solar < 1 um	99.9% (TBR)	0.1% (TBR)

As a GOAL, the HES operability should be 100% for all bands.

A.1.1.6 Temporal Requirements

A.1.1.6.1 Coverage Time

The coverage time for each region is defined as the time to produce a complete frame of data. All of the following **shall** be performed within the coverage time:

- a) Scan the required region. The coverage region is defined for this task in section A.1.1.4
- b) Scan mirror (if present) steps, settles, and slews.
- c) Spatially over-sample the scene to correct for image rotation and any other scan artifacts, in order to meet THRESHOLD sampling requirements presented in section A.1.1.5.2.
- d) Acquire the required space look and/or calibration target data needed to meet the radiometric requirements.
- e) Necessary operations to switch between tasks if one sensor is used for multiple tasks.
- f) Perform necessary operations to meet navigation requirements.

As a THRESHOLD, the OO task sensor **shall** scan the open ocean regions within the 62-degree LZA in 3 hours.

Discussion: The coverage time is specified for each of the primary scan regions for each sensor task.

As a GOAL, the OO task sensor **shall** scan the open ocean regions within the 62-degree LZA in TBD.

A.1.1.6.2 Spectral Bands Simultaneity

As a THRESHOLD, data from all spectral bands for all bands of the OO task obtained from any specific point on the Earth **shall** be coincident within 30 seconds (TBR).

As a GOAL, data from all spectral bands for all bands of the OO task obtained from any specific point on the Earth should be coincident within 20 seconds (TBR).

A.1.1.6.3 Adjacent Pixel Simultaneity

The time between collection of adjacent pixels within a single HES data frame **shall** be less than or equal to the THRESHOLD values presented in the Table A 9 below.

The time between collection of adjacent pixels within a single HES data frame should be less than or equal to the GOAL values.

Discussion: Temporal simultaneity is important for the purpose of creating images, or using retrieval information. The requirements present the maximum time between Earth measurements for adjacent pixels. When a sensor rasters a detector footprint (or array of detector footprints) across a scene to create a complete frame, these requirements determine the maximum swath length.

Table A 9 THRESHOLD and GOAL pixel simultaneity requirements

Coverage Region	Pixel Simultaneity THRESHOLD	Pixel Simultaneity GOAL
Open Ocean	18 min (TBR)	13 min (TBR)

A.1.1.6.4 Time Tagging

The data **shall** be time identified so that the time any detector sample in the data was acquired can be determined to within 0.1 milliseconds relative to the spacecraft provided clock information. The spacecraft clock is synchronized to UT as specified in the GIRD.

A.1.1.7 Radiometric Performance Requirements

A.1.1.7.1 Dynamic Range

The Reflected Solar < 1 μm band in the OO task **shall** have sufficient dynamic range for measurements between 0 and 10 (TBR) % above the “100% albedo” supplied spectrum (see appendix B) without saturation of any detector element.

Discussion: It is important to note that the 110% albedo detection does not need to be implemented on the same detector that supplies the “minimum” signal spectrum and the “maximum” signal spectrum from appendix B.

A.1.1.7.2 Measurement Precision (SNR)

The noise performance requirements are defined at the aperture of the system by the signal to noise ratio (SNR) for the OO band. The noise radiance is defined as the standard deviation (1-sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene. The signal radiance in each case is defined as the top of the atmosphere radiance (TOA) at the aperture of the system.

The SNR of the OO task sensors Reflected Solar bands and the THRESHOLD and GOAL channel centers **shall** have SNR values greater than or equal to the values plotted in Figure A 3 for nominal government supplied radiances. THRESHOLD SNR values for key wavelengths are quantified in Table A.10.

GOAL OO SNR values are shown in Figure A 3 should be greater than or equal to the values listed in Table A 10.

Typical ocean radiances are less than $100 \text{ W/m}^2/\mu\text{m/sr}$ and are provided in appendix B.

Discussion: The measurement precision is a fundamental performance metric for the GOAL tasks of HES.

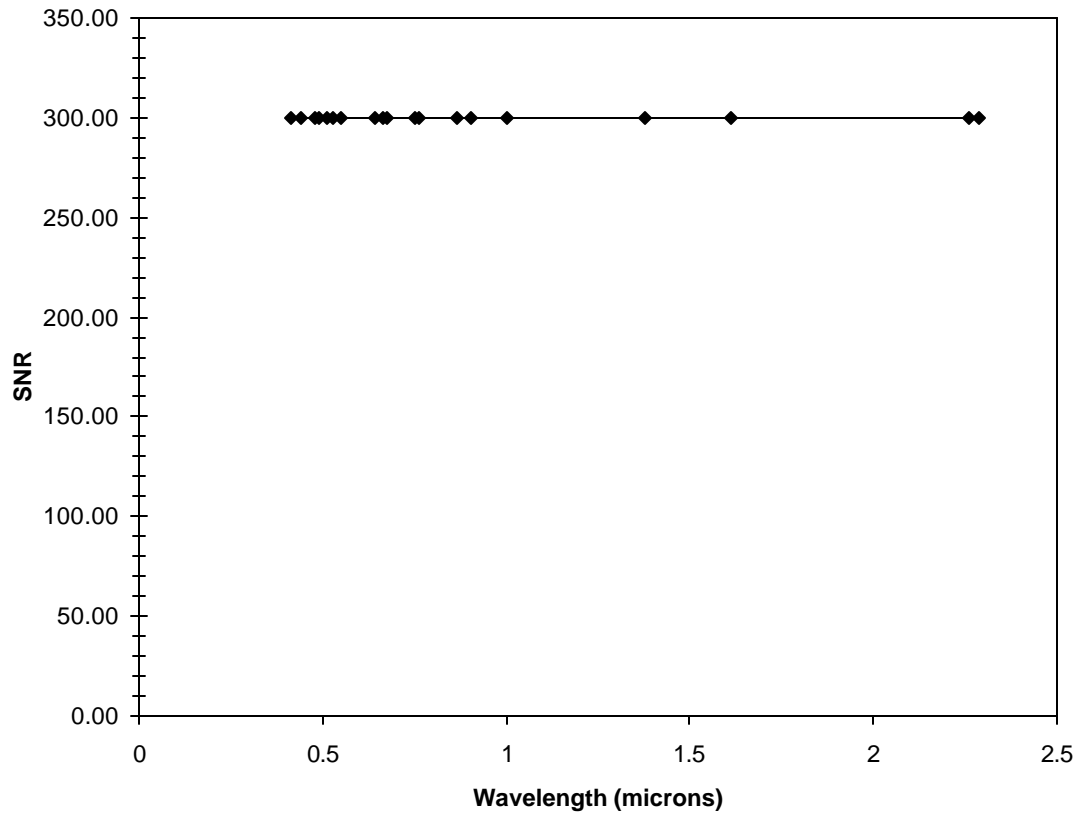


Figure A 3 Plot of OO sensor Reflected Solar SNR Requirements

Table A 10 OO Sensor Reflected Solar SNR Requirement

Channel Center (um)	Threshold SNR	Goal SNR
0.407 to 0.987 um	300 (TBR)	> 900 (TBR)
0.412 (GOAL)	300 (TBR)	> 900 (TBR)
0.443 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.477 (GOAL)	300 (TBR)	> 900 (TBR)
0.490 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.510 (GOAL)	300 (TBR)	> 900 (TBR)
0.530 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.550 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.645 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.667 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.678 (GOAL)	300 (TBR)	> 900 (TBR)
0.750 (GOAL)	300 (TBR)	> 900 (TBR)
0.763 (GOAL)	300 (TBR)	> 900 (TBR)
0.865 (THRESHOLD)	300 (TBR)	> 900 (TBR)
0.905 (GOAL)	300 (TBR)	> 900 (TBR)

A.1.1.7.2.1 Reserved

A.1.1.7.3 Radiometric Accuracy

A.1.1.7.3.1 Absolute Accuracy

The absolute accuracy **shall** be 3% of the 100% albedo with a pre-launch calibration traceable to a NIST standard.

A.1.1.7.3.2 Relative Accuracy

The relative accuracy error is defined as the root-mean-square (RMS) variation in signal level, for all measurements in an ensemble (e.g. all the pixels in a frame) illuminated by constant scene radiance.

As a THRESHOLD, the HES relative accuracy requirement for the OO task **shall** be less than or equal to the values shown in Table A 11.

The GOAL HES relative accuracy requirement for the OO task should be less than or equal to the values shown in Table A 11.

Table A 11 HES GOAL Task Relative Accuracy Requirements

Band	Rel. Accuracy (%) THRESHOLD	Rel. Accuracy (%)GOAL
Reflected Solar < 1 um	0.3% of the minimum supplied radiance per channel	0.1% of the minimum supplied radiance per channel

A.1.1.7.3.3 Long-Term Drift

The drift in absolute calibrated radiances for the OO task sensor reflective bands THRESHOLD requirement **shall** be less than 0.5 % over the instrument lifetime.

A.1.1.7.3.4 Ground Calibration

The OO reflective band THRESHOLD performance **shall** be calibrated on the ground, pre-launch.

The calibration performance requirement **shall** be a full-system and full-aperture spectral response characterization, i.e. the clear aperture of every component in the optical train is subject to calibration.

A.1.1.7.3.5 On-Orbit Calibration

As a THRESHOLD, calibration of the OO sensor Reflected Solar < 1 um band **shall** be performed on-board during the life of the instrument to meet all accuracy requirements.

An on-board, full optical train, full aperture calibrator **shall** be used to perform calibrations of the OO sensor Reflected Solar < 1 um band during the life of the instrument performing this task.

A.1.1.7.3.6 On-Orbit Electronic Calibration

A system for determining the linearity of the electronics and analog to digital converters **shall** be incorporated.

The calibration signal input non-linearity **shall** be less then 0.1% (TBR) of full scene, and the amplitude **shall** be greater than the dynamic range of the channel.

The calibration signal **shall** be inserted as close to the detector output signal as practical in the electronics chain.

A.1.1.7.3.7 Polarization Sensitivity

Polarization sensitivity is defined as the ratio of the difference between maximum and minimum output to the sum of the maximum and minimum output obtained when the plane of incoming 100% linearly polarized radiation is rotated through 180 degrees.

The OO task **shall** have less than 3% (TBR) polarization sensitivity and they should have less than 1% (TBR) polarization sensitivity.

The difference in polarization sensitivity between OO task channels **shall** be less than 2% (TBR), and should be less than 1% (TBR).

The uncertainty in the polarization sensitivity within an OO task channel **shall** be less than 1% (TBR) and should be less than 0.5% (TBR).

The polarization sensitivity requirements for the OO task **shall** be met at all Earth-viewing angles throughout the life of the mission and the sensitivity requirements should be met over the entire field-of-regard.

A.1.1.7.4 System Linearity

The corrected system radiometric response non-linearity for each detector element for the OO task **shall** be less than 1% RMS (TBR) over the full dynamic range to be stable enough to meet all radiometric performance requirements.

A.1.1.7.5 Reserved

A.1.1.7.6 Stray Light

A.1.1.7.6.1 Bright Scene Saturation

Any HES reflective band pixel (HES bands 4-6) located more than 5 (TBR) pixels away from any pixel containing a bright cloud edge of a 100% albedo source **shall** meet all performance requirements.

Discussion: Although the bright pixel edge may be small in spatial extent compared to the pixel size, the physical extent of a bright cloud edge of 100% albedo may also be many times larger than the pixel.

Any HES reflective band pixel (HES bands 4-6) located more than 3 (TBR) and less than 5 (TBR) pixels away from any pixel containing a bright cloud edge of a 100% albedo source should have a signal to noise ratio no less than half (TBR) that allowed in section 3.2.7.2.

A.1.1.7.6.2 Sun Glint

A Sun glint is defined as a signal of 200x (TBR) the 100% albedo level.

The THRESHOLD for the OO task Reflected Solar < 1 um band pixel located more than 5 (TBR) pixels away from a pixel containing a Sun glint **shall** meet all performance requirements.

The GOAL for the OO task or the HES Reflected Solar < 1 um band located more than 3 (TBR) and less than 5 (TBR) pixels away from a pixel containing a Sun glint should have a signal to noise ratio no less than half (TBR) that allowed in section A.1.1.7.2

A.1.1.7.6.2 Reserved

A.1.1.8 Image Navigation and Registration

A.1.1.8.1 INR Scope

Image navigation refers to the determination of the location of each image pixel relative to a fixed reference coordinate system. Image registration refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Mission-level Image Navigation and Registration (INR) requirements apply to pixels and encompass the combined system performance of the HES, spacecraft and ground processing system.

The HES contractor is responsible for meeting the mission-level INR requirements specified in the PORD, given the spacecraft interface specifications contained in the GOES-R UIID and GIRD. In addition to flight hardware, the HES contractor is responsible for all ground processing algorithms required to meet mission-level INR requirements.

The HES contractor will develop INR error budgets and derive requirements for all hardware and processing elements related to INR

A.1.1.8.2 INR Functions

Overview: This section defines several INR-related functions to be included in the HES and associated ground system.

A.1.1.8.2.1 Star Sensing

If star sensing is required to meet navigation requirements, the following requirements apply:

The HES **shall** have an on-board star catalog provided by the HES vendor, which is loadable and modifiable from the ground, containing an identification (ID) number, right ascension, declination, proper motion, and instrument magnitude for each star.

The HES **shall** autonomously acquire stars at a rate and accuracy required to meet INR requirements.

In addition to autonomous star sensing, the HES **shall**, when commanded, acquire stars from an HES-GS list of target stars that will be within the nominal field of regard for the next 26 hours. The target star list will consist of star ID and viewing time windows in Universal Time Coordinated (UTC) for each star.

A.1.1.8.2.2 Pointing Compensation Profiles

The HES-GS may uplink pointing compensation data for certain predictable pointing errors, such as diurnal orbit errors, thermal distortion, and sensor misalignment. The maximum range of predictive compensation will be ± 1.0 degrees north/south, east/west.

The HES **shall** include the capability to compensate its scanning profile with the uplinked correction data. Characteristics of the correction profiles are TBD.

A.1.1.8.3 INR Performance Requirements

All INR requirements listed herein apply to the end-to-end system, taking all instrument, spacecraft, and ground processing effects into account. INR errors for any given pixel(s) can be determined through analysis and simulation, while on-orbit verification will require using landmarks in an image.

Unless otherwise specified, all INR requirements in this document are specified as north/south and east/west angles, in microradians, 3-sigma, and refer to all hours of operation. In addition, 3-sigma is interpreted as the arithmetic mean, plus or minus three times the square root of the variance for a population of 100 consecutive observations.

In this section, "image" or "frame" are synonymous, and refer any programmed scan area data set ranging from a full disk down through the mesoscale in pixel space, as opposed to detector sample space. The ground sample distance (GSD) listed here is defined in section A.1.1.5.2. The ground sample angle (GSA) is associated angular distance.

A.1.1.8.3.1 Navigation

Navigation error is the angular location error of pixels or features in an image.

The navigation error for each HES GOAL task **shall** not exceed the THRESHOLD values in Table A.12 for pixels on the Earth's disk. The navigation error should not exceed the GOAL values in Table A.12.

The OO task navigation error should not degrade for the entire day.

Table A 12 HES Navigation Requirements

HES Task	THRESHOLD	GOAL
OO	0.375 GSA	0.19 GSA

A.1.1.8.3.2 Frame to Frame Registration

Frame to frame registration error is the difference in navigation error for any given pixel in two consecutive images. Since images may be 180 minutes apart, these requirements apply over 180 minute periods.

Frame to frame registration errors for the OO task **shall** not exceed the THRESHOLD values in Table A 13. Frame to frame registration error for the OO task should not exceed the GOAL values in Table A 13.

Table A 13 OO Frame-to-Frame Registration Requirements

HES Task	THRESHOLD	GOAL
OO	0.375 (TBR) GSA	0.19 (TBR) GSA

A.1.1.8.3.3 Within Frame, Non-Adjacent Pixel Registration

Within-frame, non-adjacent registration error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image.

Within-frame, non-adjacent registration error for the OO task **shall** not to exceed the THRESHOLD values in Table A 14. Within-frame, non-adjacent registration error for the OO task should not exceed the GOAL values in Table A 14.

Table A 14 OO Within-Frame, Non-Adjacent Pixel Registration Requirements

HES Task	THRESHOLD	GOAL
OO	0.375 (TBR) GSA	0.19 (TBR) GSA

A.1.1.8.3.4 Within Frame, Adjacent Pixel Registration

Within-frame, adjacent pixel registration error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line-to-line and single integration image to single integration image.

Within-frame, adjacent registration error for the OO task **shall** not exceed the THRESHOLD values in Table A 15.

Within-frame, adjacent registration error for the OO task should not exceed the GOAL values in Table A 15.

Table A 15 OO Within-Frame, Adjacent Pixel Registration Requirements

HES Task	THRESHOLD	Goal
OO	0.375 (TBR) GSA	0.19 (TBR) GSA

B RADIANCE VALUES

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All radiance values plotted here are available in a single spreadsheet. Information is now available from the GOES HES project library at NASA/GSFC by contacting the GSFC GOES Program Office at (301)-286-9840. For the HES-CW task radiances, please note the headings in the spreadsheet.

B.1 IR Radiance Values

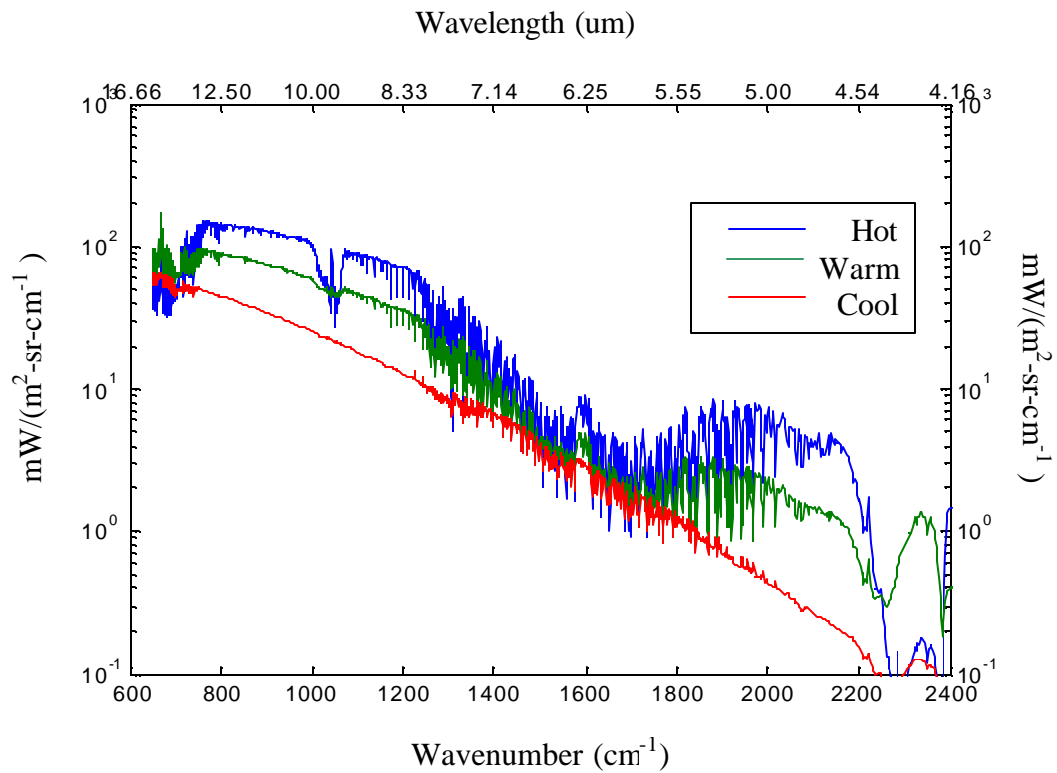


Figure B 1. Radiance Values for sounding task sensor(s)

B.2 Reflected Solar Radiance Values (TBS)

HES-CW continuous radiance value updates

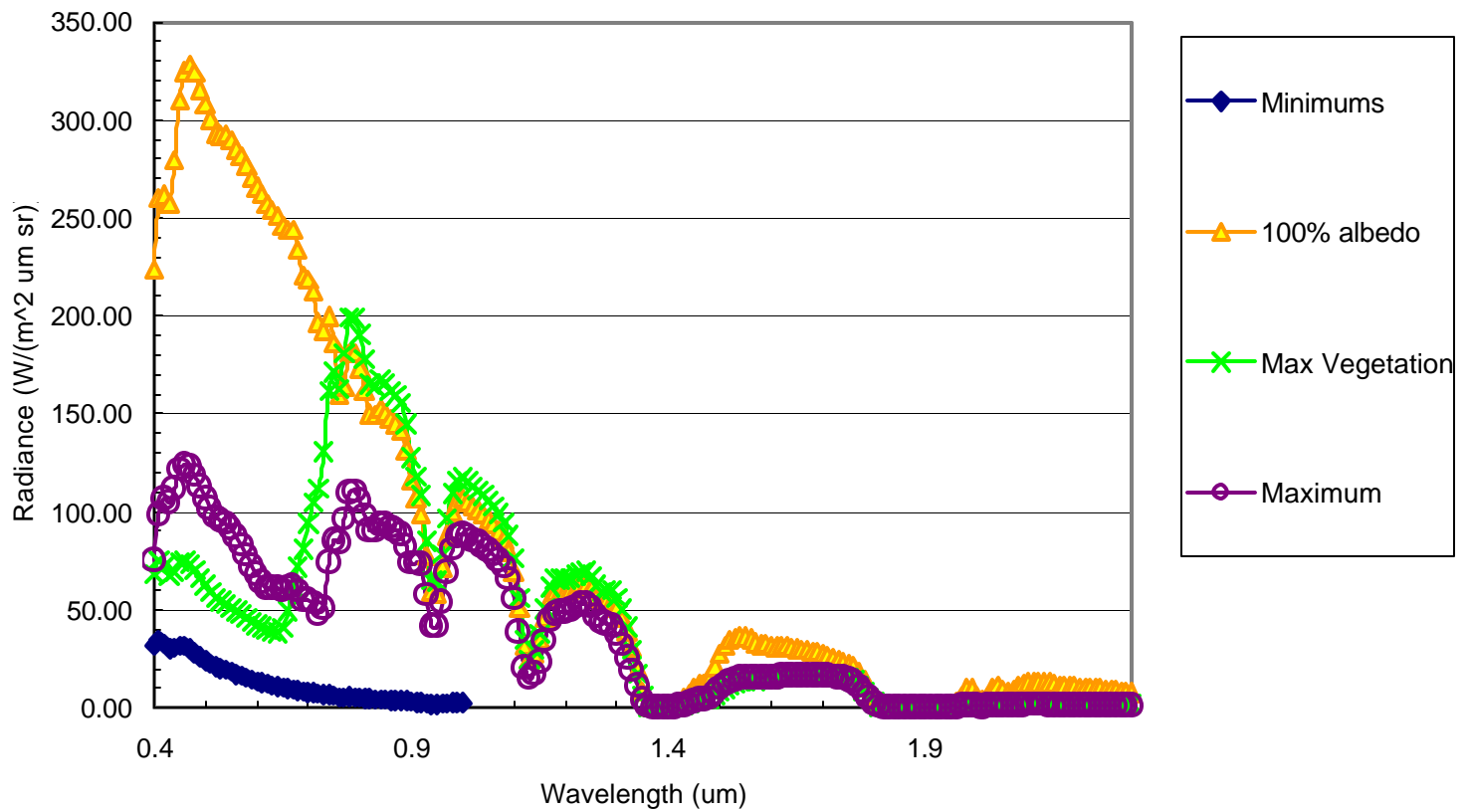


Figure B 2. Radiance Values for CW task sensor

C ACRONYMS AND ABBREVIATIONS

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ABI	Advanced Baseline Imager
ACS	Attitude Control System
AJ	As Justified
AME	Angular Measurement Error
APE	Absolute Pointing Error
ASTM	American Society for Testing and Materials
CONUS	Continental United States
CW	Coastal Waters
DOEE	Detector Optics Ensquared Energy
DS	Disk Sounding
FOR	Field of Regard
FOV	Field of View
GIFTS	Geostationary Imaging Fourier Transform Spectrometer
GIRD	General Interface Requirements Document
GOES	Geostationary Operational Environmental Satellite
GS	Ground System
GSA	Ground Sample Angle
GSD	Ground Sample Distance
GSFC	Goddard Space Flight Center
GSR	Ground Sample Rate
HES	HYPERSPPECTRAL ENVIRONMENTAL SUITE
ID	Identification
IDD	Instrument Definitions Document
IEEE	Institute of Electrical and Electronics Engineers
IFOV	Instantaneous Field of View
INR	Image Navigation and Registration
IR	Infrared
LWIR	Longwave Infrared
LZA	Local Zenith Angle
MRD	Mission Requirements Document
MTF	Modulation Transfer Function
MW	Midwave
MWIR	Midwave Infrared
NA	Not Applicable
NAS	National Aerospace Standard
NASA	National Aeronautics and Space Administration
NEdN	Noise Equivalent Change in Radiance
NEdT	Noise Equivalent Change in Temperature
NER	Noise Equivalent Radiance
NESR	Noise Equivalent Spectral Radiance
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
OO	Open Ocean
PORD	Performance and Operation Requirements Document

PSF	Point Spread Function
RFP	Request for Proposals
RMS	Root Mean Square
SI	International System of Units
SNR	Signal to Noise Ratio
SOW	Statement of Work
SRF	Spatial Response Function
SSF	Scene Spread Function
SSP	Sub Satellite Point
SW	Shortwave
SWIR	Shortwave Infrared
TBD	To Be Determined
TBR	To Be Reviewed
TBS	To Be Specified
TDI	Time Delay Integration
TOA	Top of the Atmosphere
UIID	Unique Instrument Interface Document
US	United States
UT	Universal Time
UTC	Coordinated Universal Time

D DEFINITIONS DOCUMENTATION

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Absolute Radiometric Accuracy: The unknown bias error in the measured radiance in each spectral channel, root-mean-squared with any random precision or repeatability component in a specific measurement period.

Applicable Document: Document that mandates requirements

Band: A set of spectral channels.

Channel: A measurement within a band that is an aggregate of one or more spectral samples that meets or exceeds HES threshold requirements.

Coastal Waters: Ocean waters within 400 km from the shore along the length of the US coast (east and gulf coast: ~6000 km, US west coast ~2100 km).

CONUS (CONTinental United States): A rectangle, approximately 3000-km by 5000-km encompassing the entire geographic extent of the 48 contiguous United States.

Co-Registration: The difference in pointing between channels for any given pixel in the same frame.

Coverage: Refers to the equivalent area of the Earth, centered at nadir, from which a set of data products is collected. It is defined as the area projected onto a plane tangent to the surface of the earth at the sub-satellite point over which the FOV is to be scanned.

Coverage Time: The time to produce a complete frame of data for each region.

Cross-Talk: The electrical and optical energy that is coupled into a detector from any other detector in the same array of detectors.

Detector: A device that converts electromagnetic radiation into an electrical signal. The reference to “detector data” corresponds to digital output following the analog-to-digital conversion.

Detector/Optics Ensquared Energy (DOEE): The detector/optics ensquared energy (DOEE) is a unitless figure of merit, which is the ratio of the energy *measured by* a detector from its corresponding ground sample area (defined by the Threshold GSD (TGSD), not the detector active-area projection on the ground) to the energy *measured by* the detector from the entire large and uniform scene.

Detector Sample: Digitized output from a single detector element.

Field of Regard: The angular extent to which the field of view of the HES can be directed without obstruction.

Field of View (FOV): The angle subtended by the geometric projection of the entire detector array to the surface of the Earth or the far-field angle subtended by the entire detector array.

Frame: A collection of observations that together form a spatially contiguous data set that might be analyzed to characterize the radiation from the Earth-atmosphere system. A complete scan of a region defines

Full Disk Region: A 17.76-degree diameter circle centered at nadir, as seen from each satellite

Goal: Requirements that would greatly enhance the utility of the data if they were met.

Ground Sample Distance (GSD): The centroid-to-centroid distance between adjacent spatial samples on the Earth's surface, as measured at the satellite sub point.

Ground Sample Rate (GSR): Mandates the number of full-spectrum Earth spatial samples that must be collected per unit time.

Hyperspectral: (contiguous channels)

Image Navigation: Refers to the determination of the location of each image pixel relative to a fixed reference coordinate system.

Image Registration: Refers to maintaining the spatial relationship between pixels within image frames and between image frames.

Inoperable Spectral Channel: A single spectral resolution element with noise equivalent radiance greater than two times the required measurement precision.

Instantaneous Field of View (IFOV): The angle subtended by the geometric projection of a single detector to the surface of the Earth at nadir or the far-field angle subtended by a single detector.

Local zenith: The vector normal to the surface of the Earth at a ground location. In other words, the local zenith lies along a radial vector extended from the center of the Earth through the surface of the Earth at a given ground location.

62-degree Local Zenith Angle (LZA) Region: The 62-degrees local zenith angle region minus half of the region of overlap that occurs between the east and west satellites.

Mesoscale: A rectangular region of arbitrary size up to the equivalent of a 1.6-degree by 1.6-degree (~1000-km by 1000-km) nadir-viewed area.

Nadir: The point on the Earth intercepted by a line drawn from the centroid of the satellite to the center of the Earth.

Noise Equivalent Radiance (NER, NEdN) [mW/m²·sr] or Noise Equivalent Spectral Radiance (NESR) [mW/m²·sr·cm⁻¹]: A nominal way of describing noise and random errors in the measuring system. Sources of noises typically include detector shot noise, thermal noise, and readout noise terms. Since these terms include shot noise, the effective scene temperature must be included.

Noise Equivalent Delta Temperature (NEdT) [K]: The NER in terms of temperature units. The NEdT is defined as NEN divided by the radiance derivative with respect to temperature. The NEdT is a value, which depends on the temperature of the scene being observed and the spectral region of the observation.

Noise Radiance: The standard deviation (1 sigma) of the calibrated radiance in each spectral channel over many measurements while viewing the same scene.

Pixel: All spectral samples associated with data samples from a given field of view after processing, including calibration and navigation.

Pixel Binning: The combination of several pixels to form a single picture element (pixel).

Reference Document: A document that only supplies more information.

Registration Error: There are two types of registration error:

1. Non-Adjacent Registration Error is the difference between the measured and nominal distance between any two non-adjacent pixels in an image.
2. Adjacent Registration Error is the difference between the measured and nominal distance between any two adjacent pixels in an image, including line-to-line and single integration image to single integration image.

Relative Radiometric Accuracy: The unknown bias error *between two arbitrary radiance measurements*, root-mean-squared with any random precision or repeatability component in a specific measurement period.

Scene temperature: The effective temperature of the scene being viewed. This temperature differs from the radiance temperature of the surface due to emissivity, reflectance, and atmospheric attenuation of the radiation.

Signal Radiances: The radiance arriving from the top of the atmosphere (TOA).

Spectral Sample: A measurement within a channel that may or may not be aggregated for transmission to the ground.

Sub-Satellite Point (SSP): see Nadir.

Swath: One traversal of the field of view in the east-west directions over the entire scene of interest.

TBD: Meaning "to be determined" is applied to a missing requirement. The missing requirement will be determined through the course of the contract execution.

TBR: Meaning "to be reviewed" implies that the requirement is subject to review for appropriateness by the contractor or the government. The government may change "TBR" requirements in the course of the contract.

TBS: Meaning "to be specified", indicates that the government will supply the missing information in the course of the contract.

Threshold Channel: A channel with a HES threshold spectral resolution element width. (see section 3.2.2)

THRESHOLD: The minimum performance characteristic that is acceptable.

Transfer orbit: The sequence of events that transpires to establish the GOES-R series satellite on-station after the GOES-R series satellite has separated from the launch vehicle.

Within Frame Scan Efficiency: A metric describing the fraction of time spent collecting Earth scene measurements in one complete frame.

Zenith Angle: The angle measured from the local zenith to the line-of-sight to the spacecraft.